Rivers in the Sky: Recent Developments in Atmospheric River Science and Applications for California

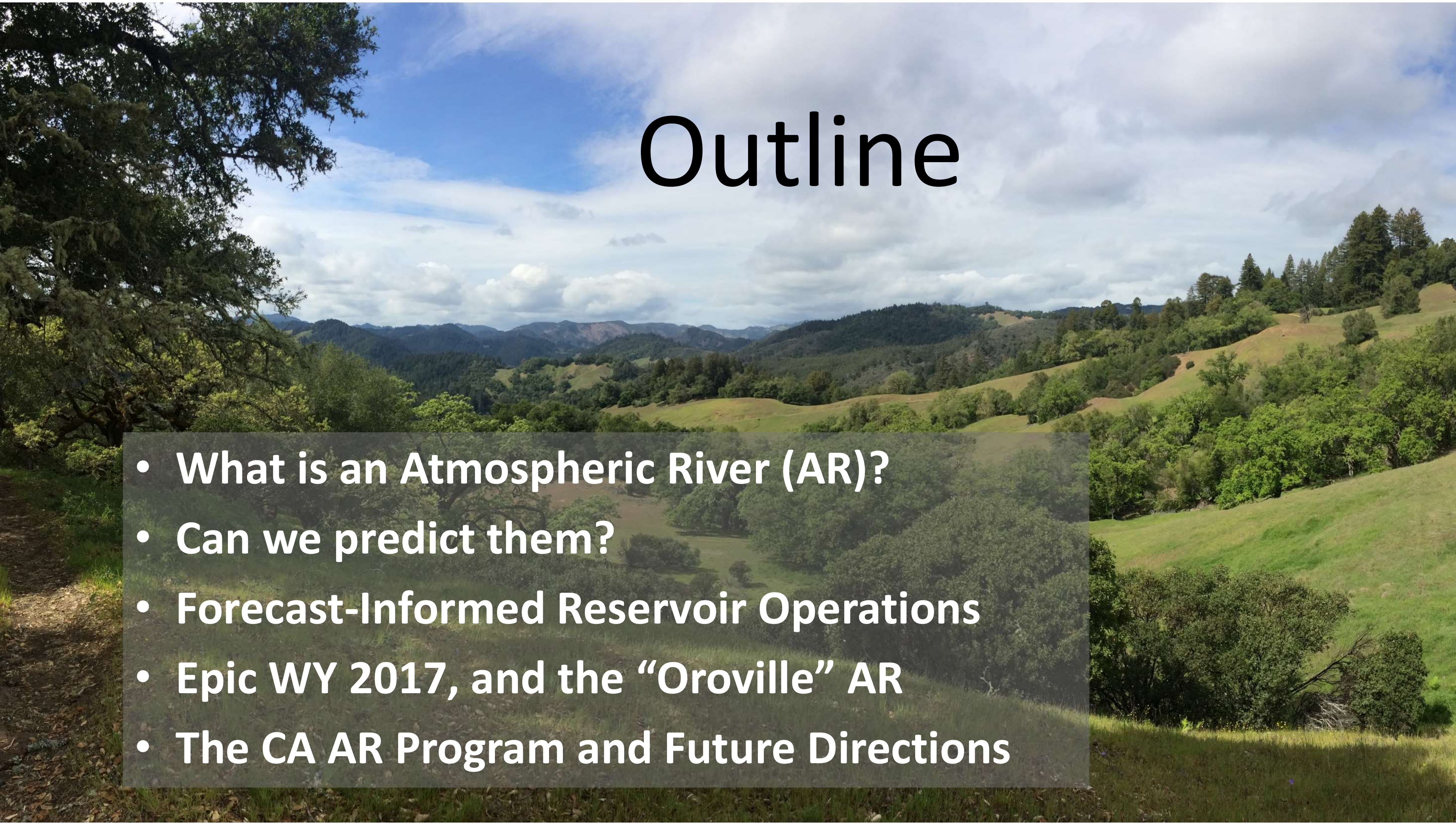
F. Martin Ralph
Center for Western Weather and Water Extremes
UC San Diego/Scripps Institution of Oceanography

California Department of Water Resources
“Watershed University” Webinar, 25 Sept 2018

California Central valley in flood on 21 January 2017 near Sacramento

Photo courtesy John Nielson-Gammon

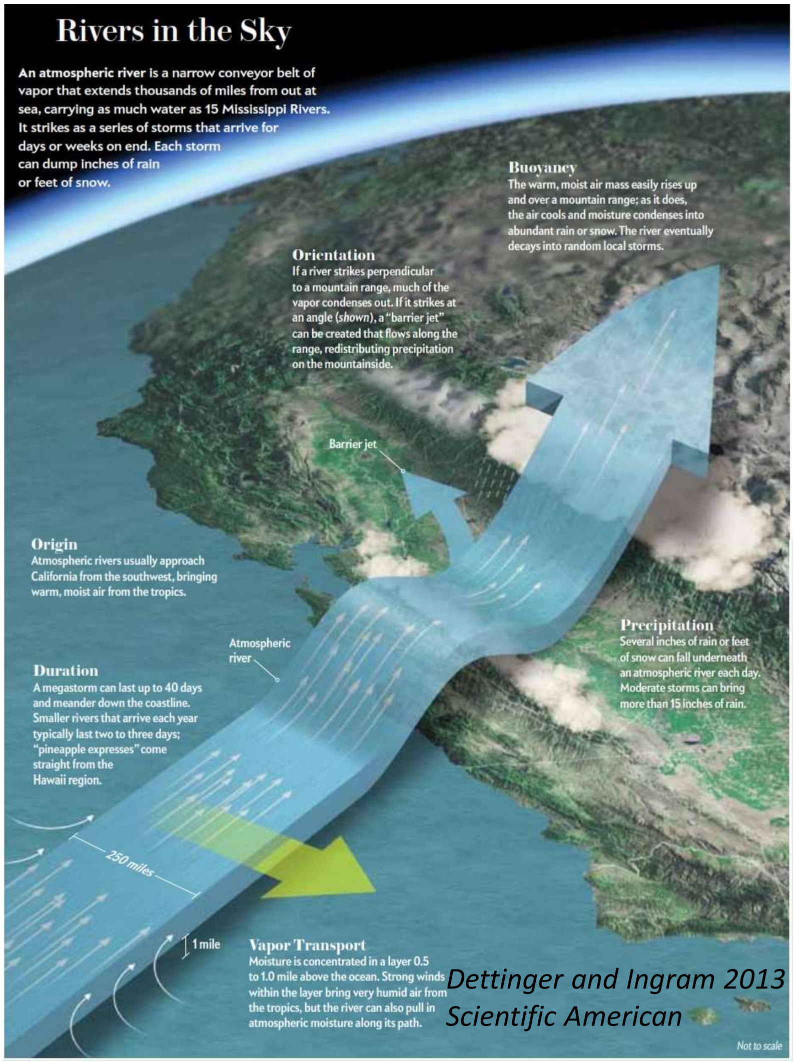
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO



Outline

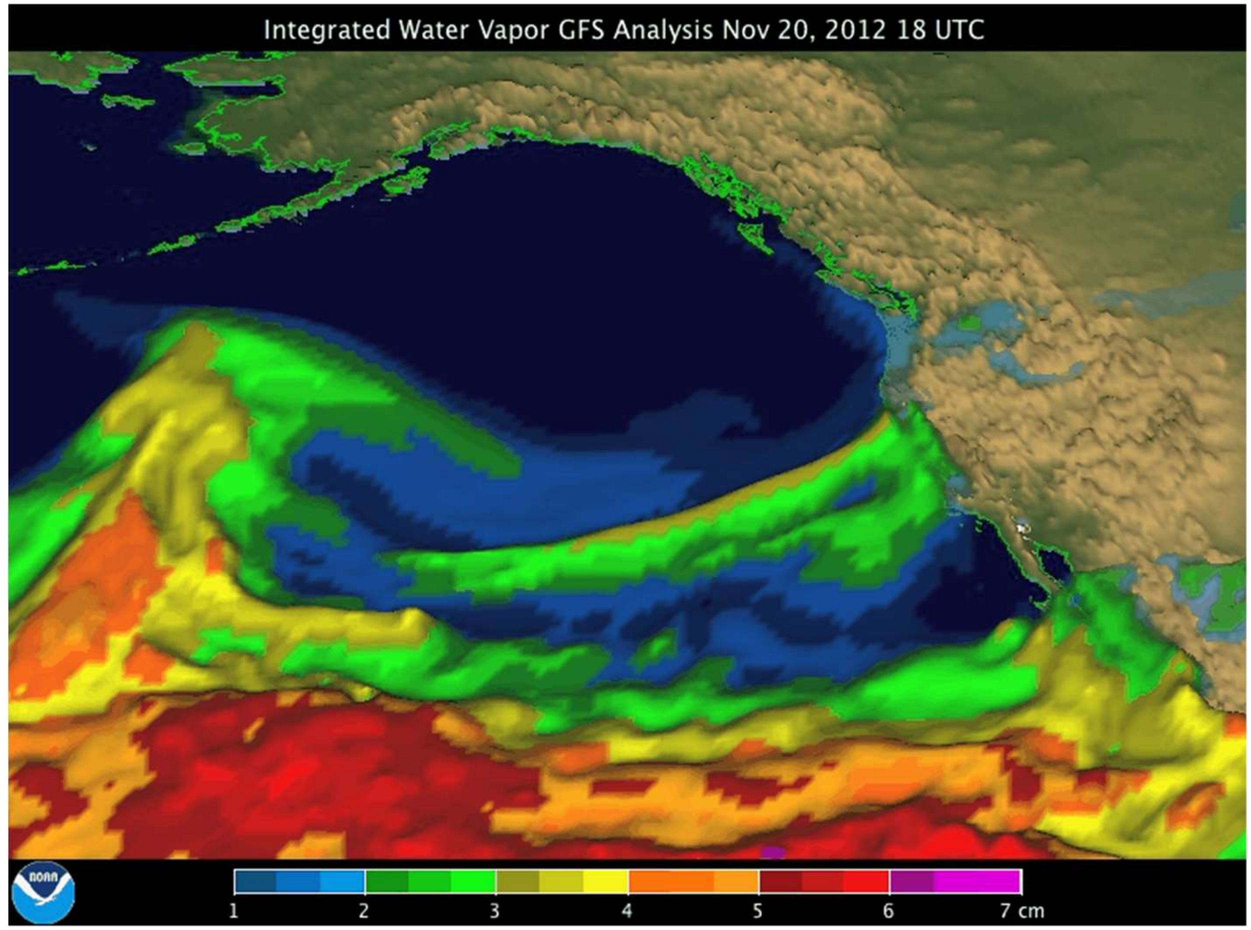
- **What is an Atmospheric River (AR)?**
- **Can we predict them?**
- **Forecast-Informed Reservoir Operations**
- **Epic WY 2017, and the “Oroville” AR**
- **The CA AR Program and Future Directions**

Rivers in the Sky



Dettinger and Ingram 2013 Scientific American

Atmospheric River Events 20 Nov-3 Dec 2012

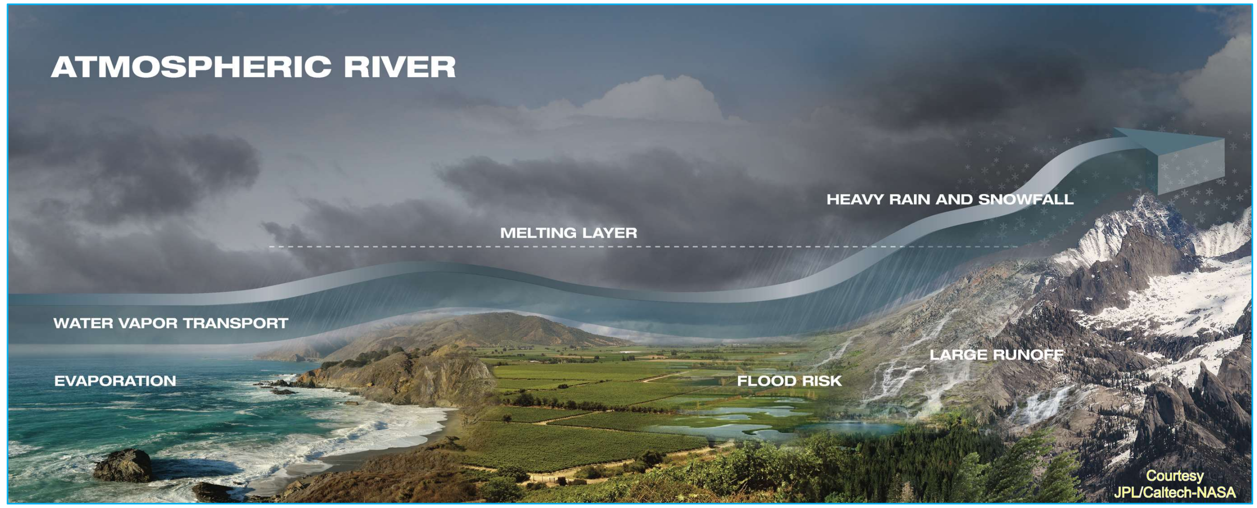


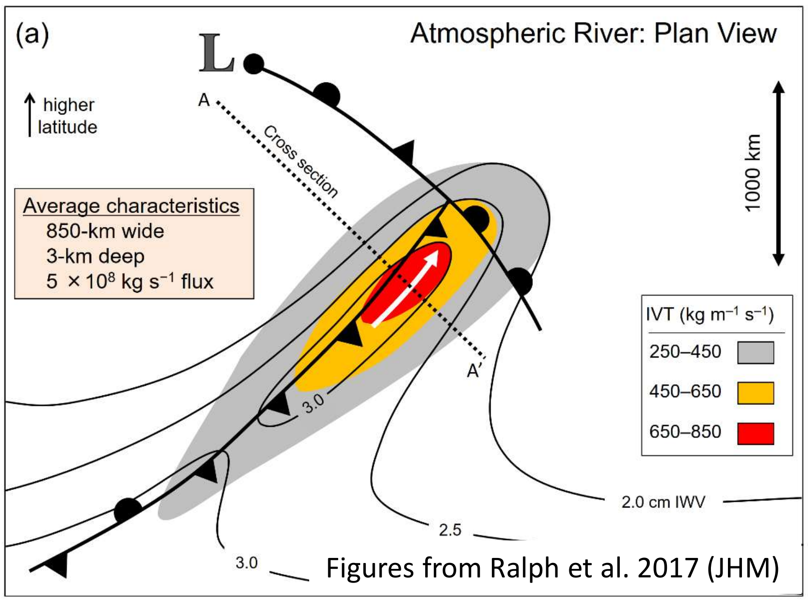
Animation courtesy of Don Murray (NOAA/ESRL/PSD)

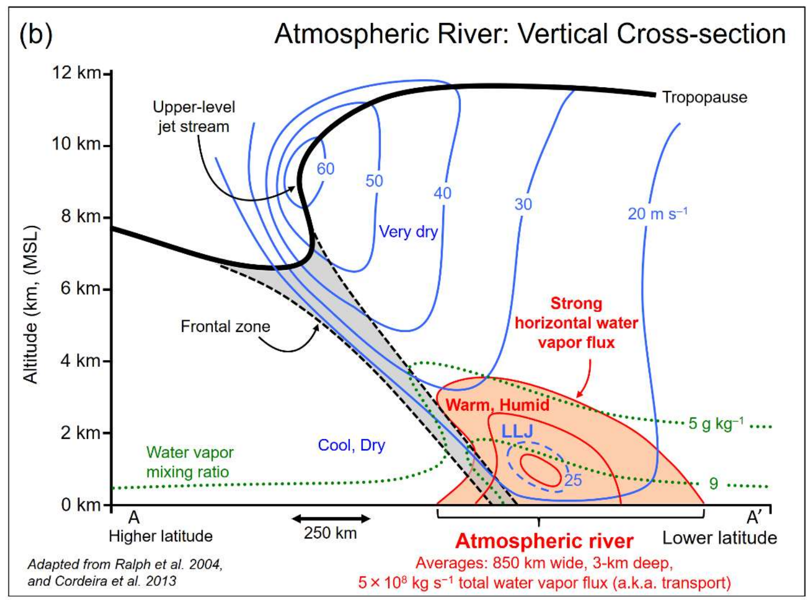
Glossary of Meteorology
Added May 2017

ATMOSPHERIC RIVER

A long, narrow and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone. The water vapor in atmospheric rivers is supplied by tropical and/or extratropical moisture sources. Atmospheric rivers frequently lead to heavy precipitation where they are forced upward, e.g., by mountains or by ascent in the warm-conveyor-belt. Horizontal water vapor transport in the mid-latitudes occurs primarily in atmospheric rivers and is focused in the lower troposphere.



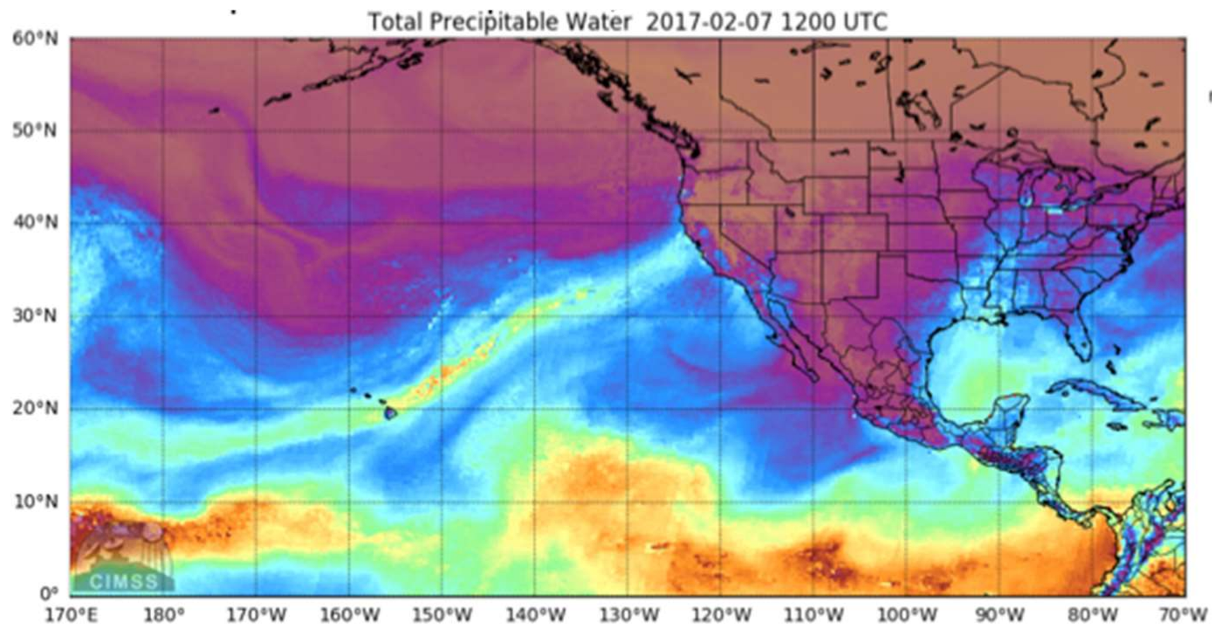


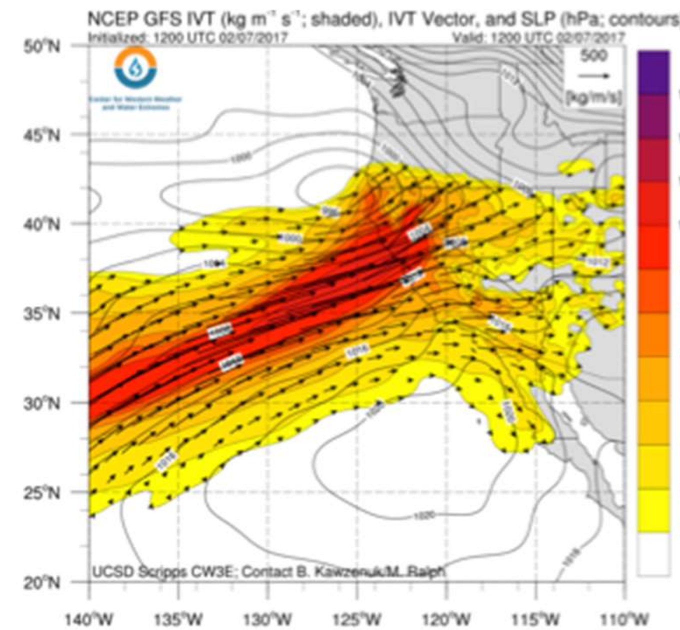


Figures from Ralph et al. 2017 (JHM)

Summary of the process of developing the formal AR definition for the Glossary: Ralph et al. (2018, BAMS)

Was the Oroville Incident Related to an AR?





Yes. An AR of "**Extreme"** intensity hit the area.

And, it was an "**AR-CAT 4**" on the new AR Scale, based on its "intensity" and its duration.

Dropsonde Observations of Total Integrated Water Vapor Transport within North Pacific Atmospheric Rivers

F.M. Ralph, S. Iacobellus, P.J. Neiman, J. Cordeira, J.R. Spackman, D. Waliser, G. Wick, A.B. White, C. Fairall

J. Hydrometeorology (2017)

Method/Data: Uses 21 AR cases observed in 2005 - 2016 with full dropsonde transects.

- AR edges best defined by using IVT = 250 kg m^{-1} s^{-1}

Conclusions*:

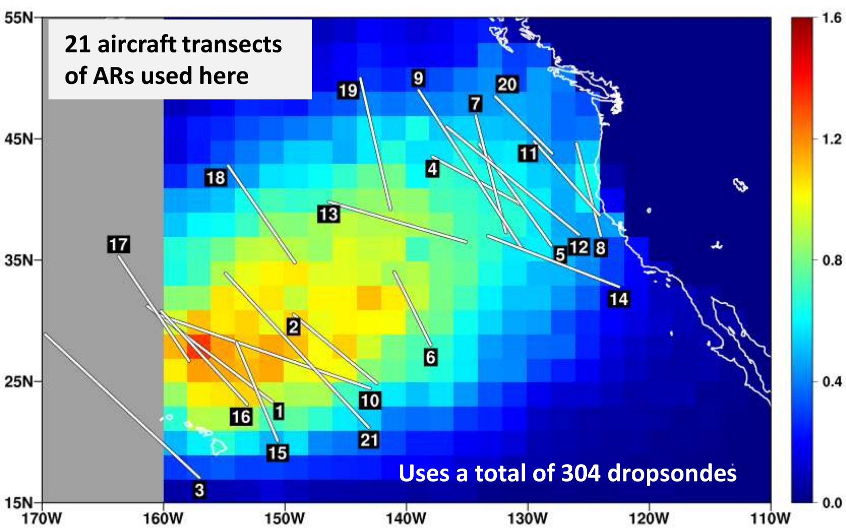
- Average width: 850 km
- 75% of water vapor transport occu
  3 km MSL; < 1% occurs above 8 km
- Average max IVT: ~800 kg m^{-1} s^{-1}

KEY FINDING

An average AR* transports 4.7 ± 2.0 x 10^8 kg s^{-1} of water

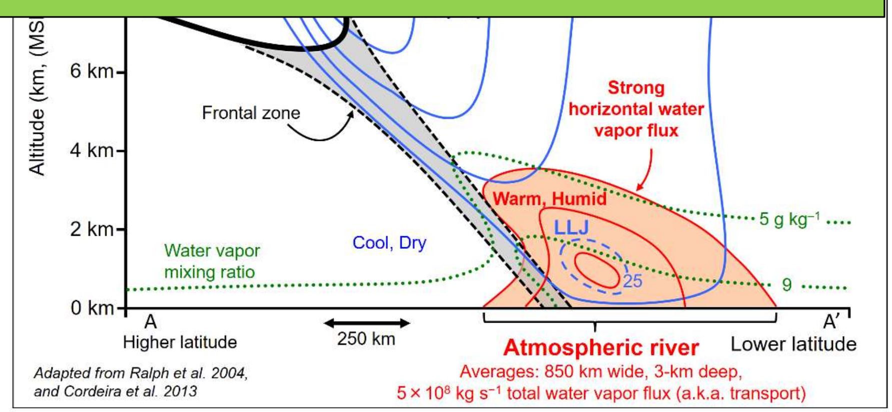
An average AR transports (as water vapor) the equivalent of

- **25 times the average discharge of the Mississippi River (as liquid), or**
- **25 M acre feet/day**

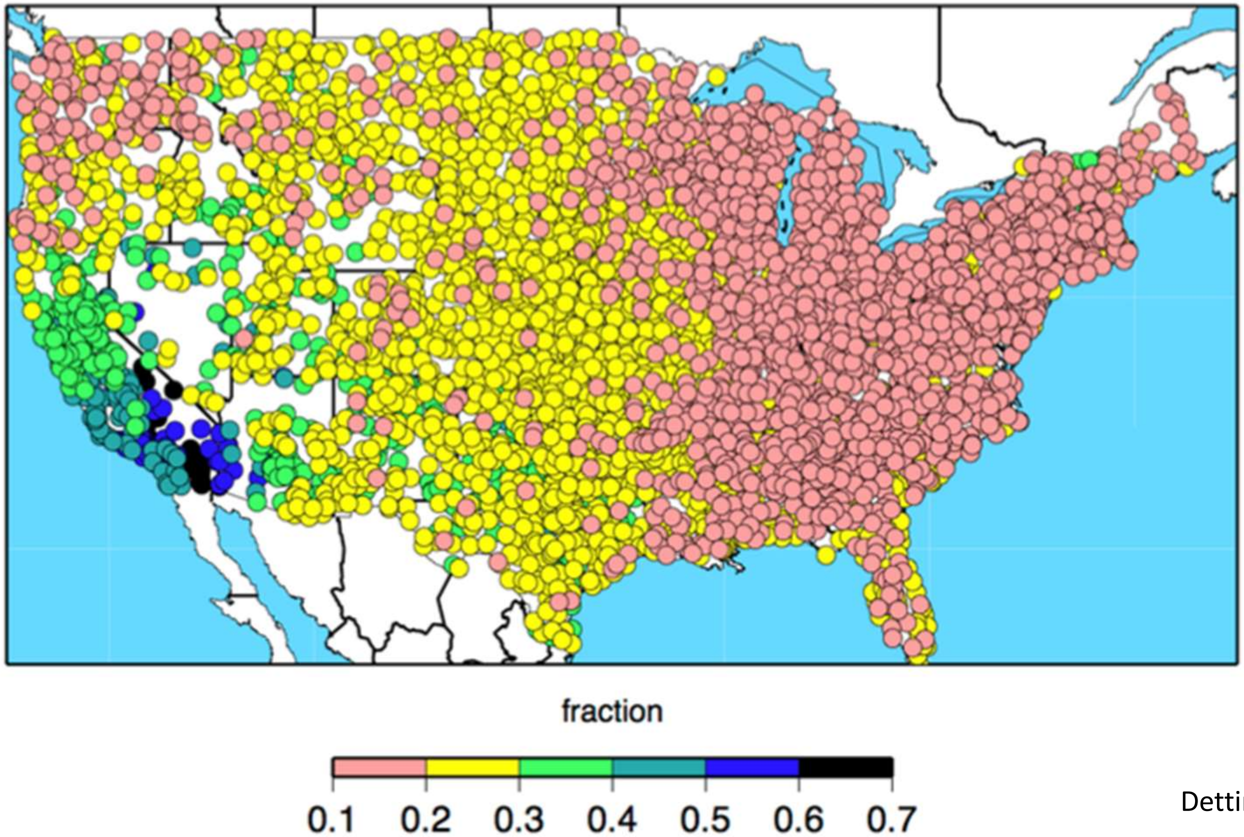


averages for the Northeast Pacific Ocean in the January-March season

Background image denotes weekly AR frequency during cool seasons (Nov -Feb).



Variability of Annual Precipitation



Coefficient of variation for annual precipitation 1950-2008

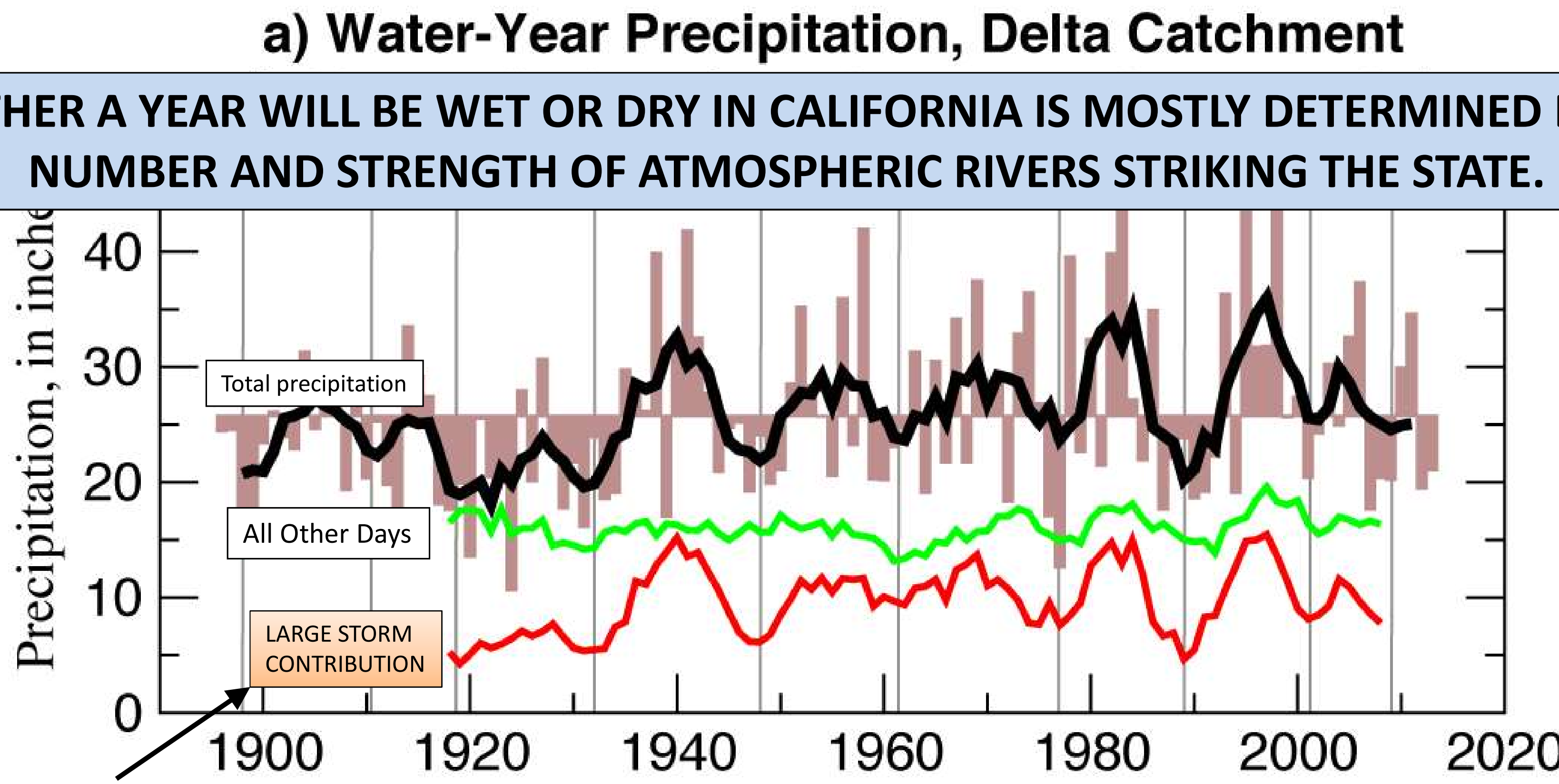
- CA has the largest year to year precipitation variability in the US.
- CA variability is on the order of half the annual average.
- The year to year variability in CA is largely caused by the wettest days (ARs).

Dettinger, M.D., Ralph, F.M., Das, T., Neiman, P.J., and Cayan, D., 2011: **Atmospheric rivers, floods, and the water resources of California**. *Water*, **3**, 455-478.

A few large storms (or their absence)

account for a disproportionate amount of California's precipitation variability

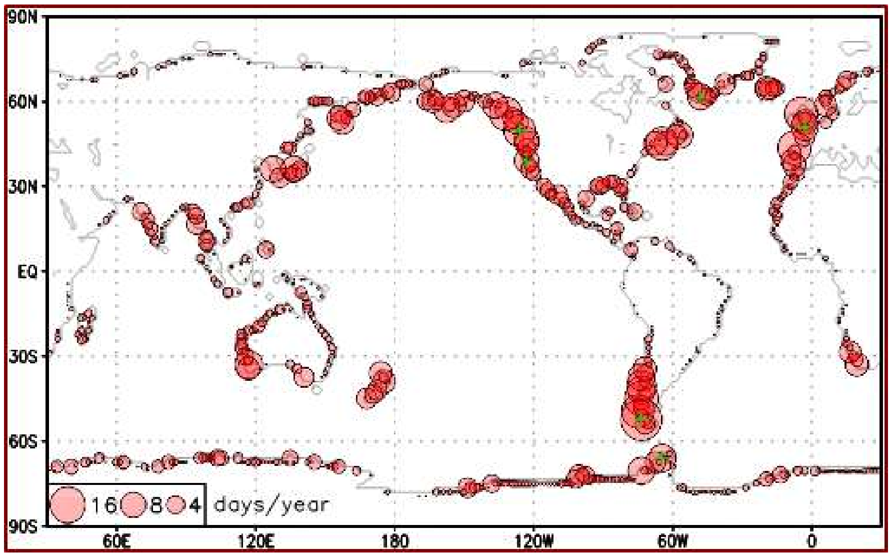
WHETHER A YEAR WILL BE WET OR DRY IN CALIFORNIA IS MOSTLY DETERMINED BY THE NUMBER AND STRENGTH OF ATMOSPHERIC RIVERS STRIKING THE STATE.



- 85% of interannual variability results from how wet the 5% wettest days are each year.
- These days are mostly atmospheric river events.

Dettinger and Cayan **Drought and the Delta—A Matter of Extremes**
San Francisco Estuary and Watershed Science, April 2014

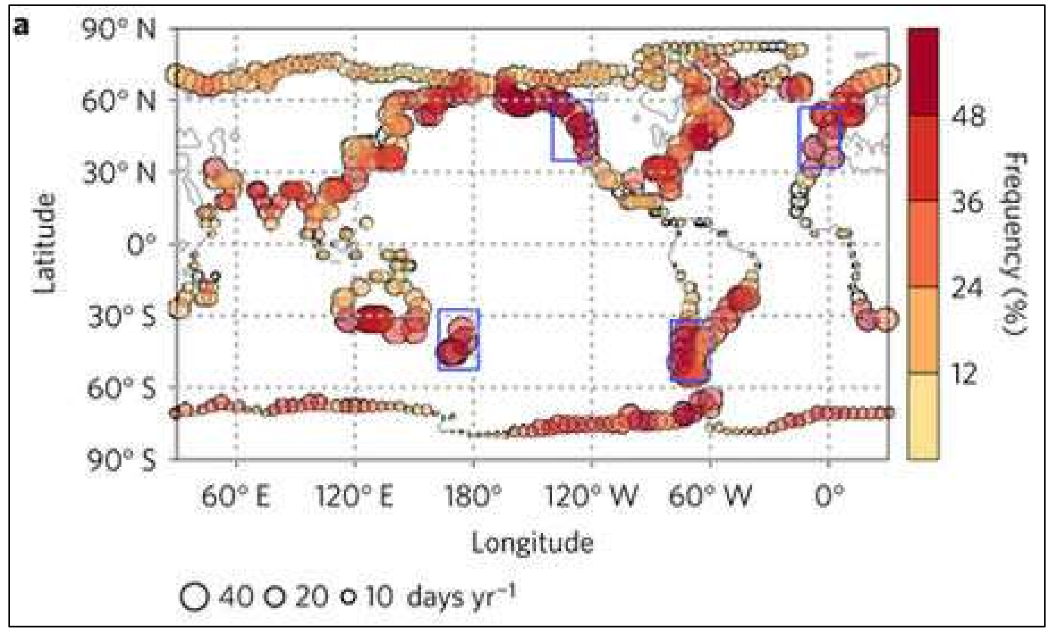
Where do Atmospheric Rivers Make Landfall Globally?



Locations (dots), and frequencies (dot sizes) of landfalling atmospheric rivers

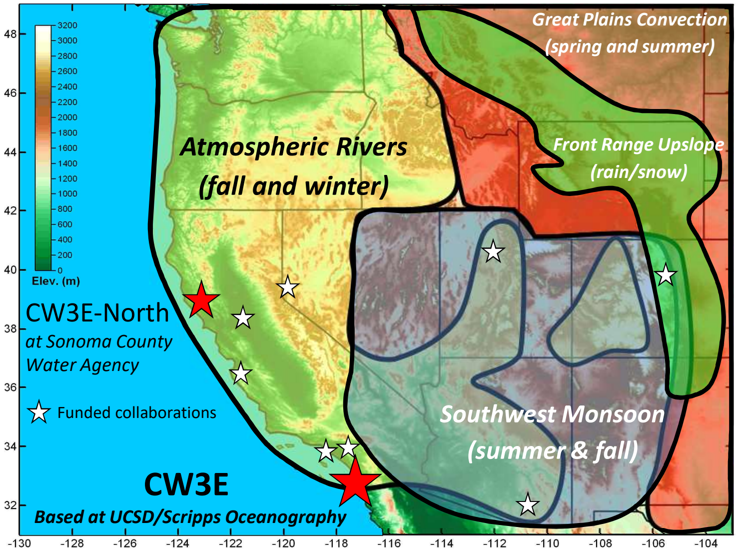
Guan and Waliser, 2015 (JGR)

Relationship Between Coastal Extreme Surface Winds and AR Landfall?



Percentage of coastal extreme surface winds events that are associated with landfalling atmospheric rivers (color fill), and frequency of occurrence (dot size).

Waliser and Guan, 2017 (Nat. Geoscience)



Key Phenomena Causing Extreme Precipitation in the Western U.S. (Ralph et al. 2014)

Center for Western Weather and Water Extremes

SCRIPPS INSTITUTION OF OCEANOGRAPHY
AT UC SAN DIEGO

Director: F. Martin Ralph, Ph.D. **Website: cw3e.ucsd.edu**

Strategies: Observations, physical processes, modeling, decision support

Partners: California DWR, Sonoma County Water Agency, CNAP, USGS
San Diego Supercomputing Center

Sponsors: CA DWR, USACE/ERDC, NOAA, SCWA, NASA, USBR

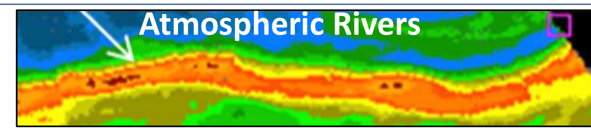
Mission

Provide 21st Century water cycle science, technology and outreach to support effective policies and practices that address the impacts of extreme weather and water events on the environment, people and the economy of Western North America

Goal

Revolutionize the physical understanding, observations, weather predictions and climate projections of extreme events in Western North America, including atmospheric rivers and the North American summer monsoon as well as their impacts on floods, droughts, hydropower, ecosystems and the economy

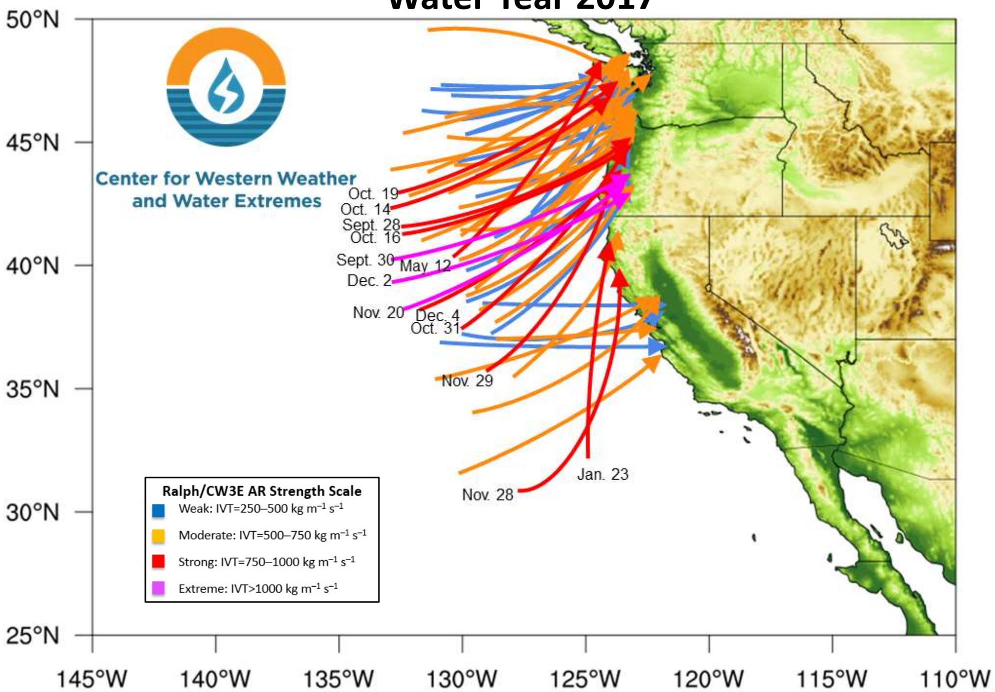
CW3E's Core Efforts



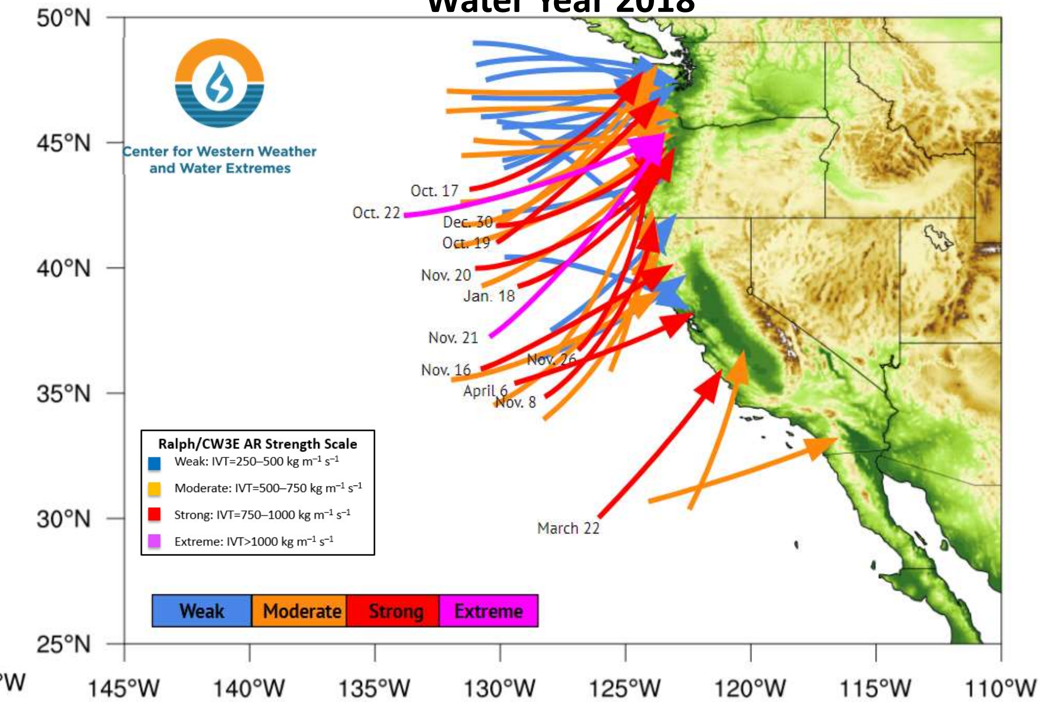
WY 2018 Compared to WY 2017

- The record breaking WY 2017 experienced a total of 68 landfalling ARs over the U.S. West Coast
- 60 of the total 68 ARs occurred through April 2017, compared to 44 experienced this WY through April

Water Year 2017

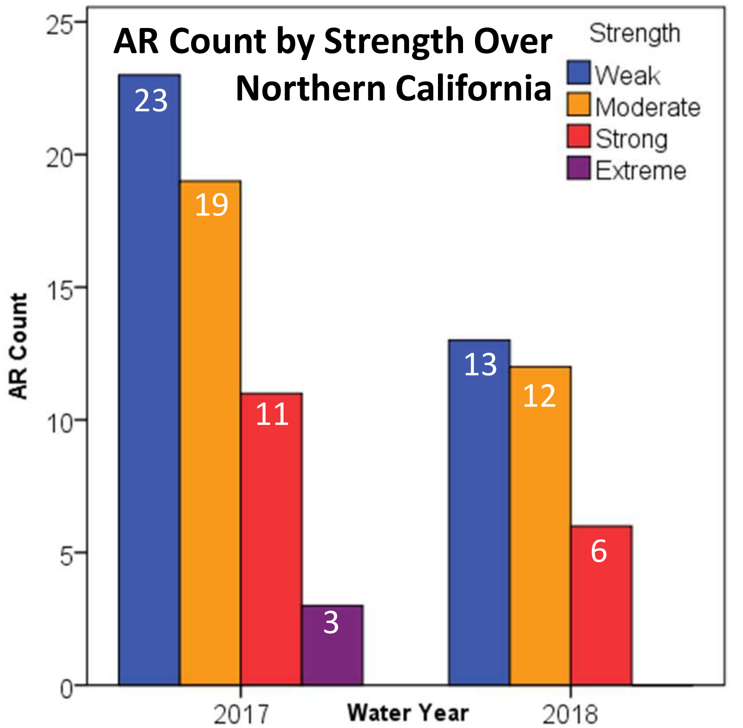


Water Year 2018

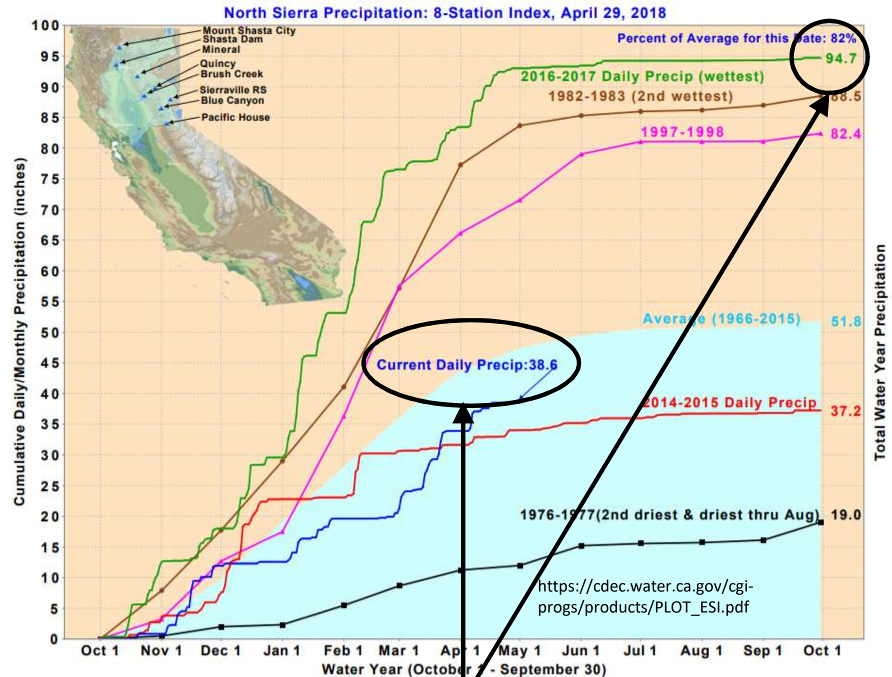


- When compared to WY 2017, a larger proportion of landfalling ARs during WY 2018 made landfall over the Pacific Northwest

Northern California Analysis



- 42 weak or mod. ARs occurred over Northern CA during WY 2017, compared to 25 during WY 2018
- WY 2017 also experienced 14 strong or extreme ARs compared to only 6 strong ARs during WY 2018



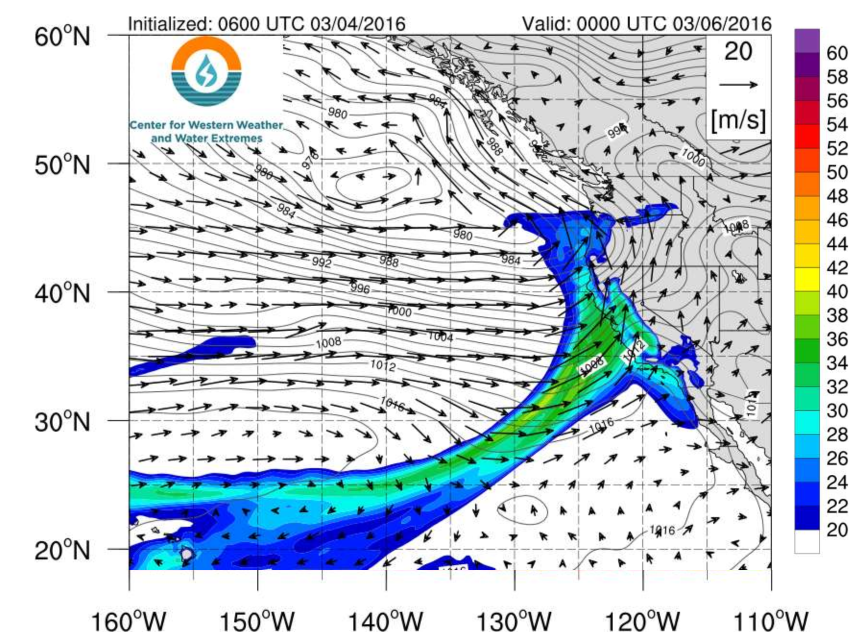
- The differences in frequency and strength of landfalling ARs resulted in large differences in WY precipitation over the Northern Sierra 8-Station Index
- The index received ~56 more ins. of precipitation during WY 2017 than WY 2018 to date (94.7 in. vs. 28.6 in.)

Can We Predict ARs? YES!..... To a degree.

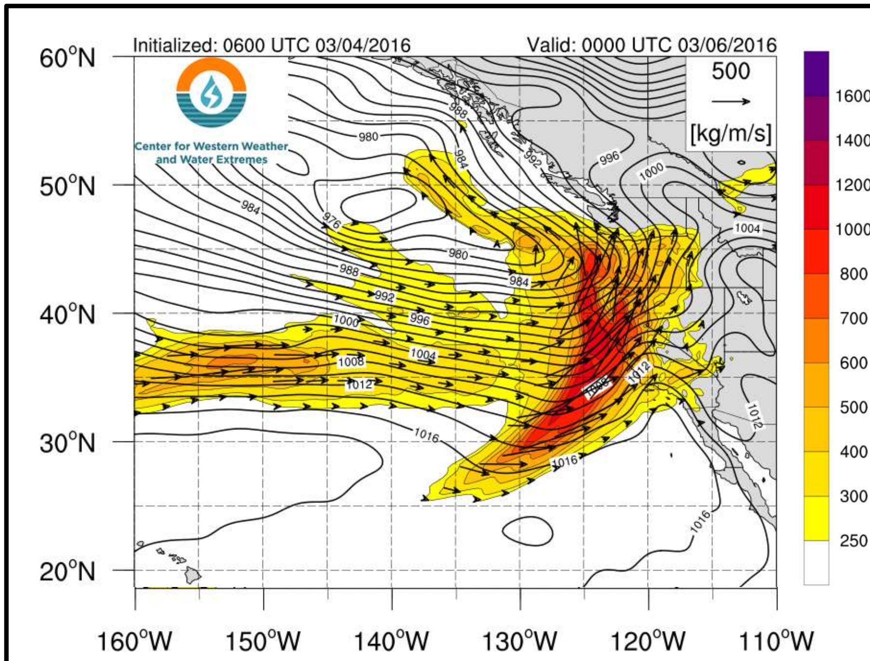
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Incoming storm of 5-7 March 2016 has characteristics of an atmospheric river
- Strikes mostly northern and central California
- Moderate strength
- Average duration at landfall (12-24 hours)

Example of a 2 day lead-time forecast



NCEP GFS IWV (mm; shaded), 850-hPa Wind (vectors), and SLP (hPa)



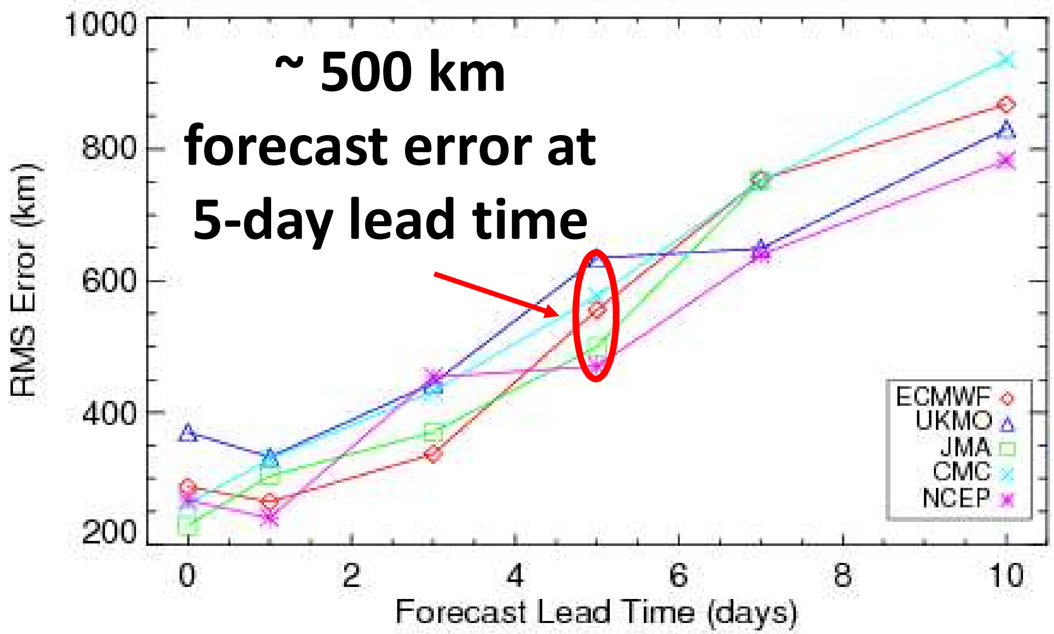
NCEP GFS IVT (kg/m/s; shaded), IVT Vector, and SLP (hPa; contours)

Summary by F.M. Ralph 8 AM PT Fri 4 March 2016

AR Landfall Position Forecast Errors Quantified

While overall occurrence well forecast out to 10 days, landfall is less well predicted and the location is subject to significant errors, especially at longer lead times

RMS Error in Forecast AR Landfall Location



- Errors in location increase to over 800 km at 10-day lead
- Errors in 3-5 day forecasts comparable with current hurricane track errors
- Model resolution a key factor

From Wick et al., 2013 (Weather and Forecasting)

- **Models provide useful heads-up for AR impact and IWV content, but location highly uncertain**
- **Location uncertainty highlights limitations in ability to predict extreme precipitation and flooding**
- **Improvements in predictions clearly desirable**

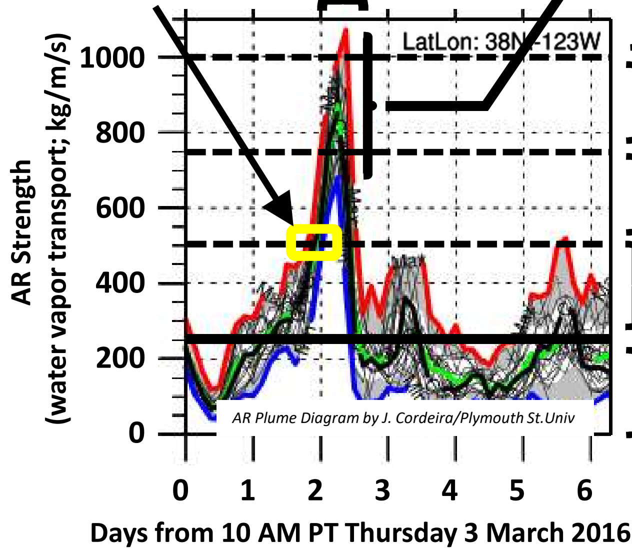
A Scaling for Atmospheric River Intensity

Example is from a CW3E "AR Outlook" posted 4 March 2016 for Pt Reyes, CA area, including the Russian River

Onset of moderate-strength AR conditions Saturday morning

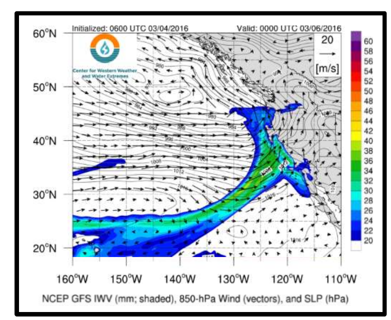
Normal-duration AR landfall (12-24 hours)

Max AR strength is uncertain by +/- 20%



General Impacts

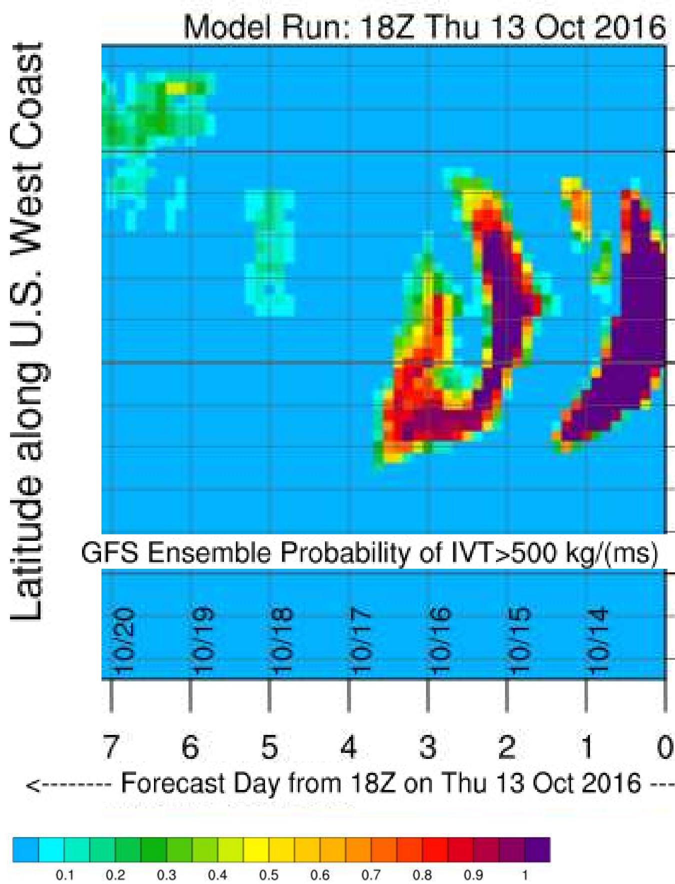
Extreme AR	**Hazardous**
Strong AR	**Hazardous & Beneficial**
Moderate AR	**Beneficial & Hazardous**
Minimal AR	**Beneficial**
Not an AR	

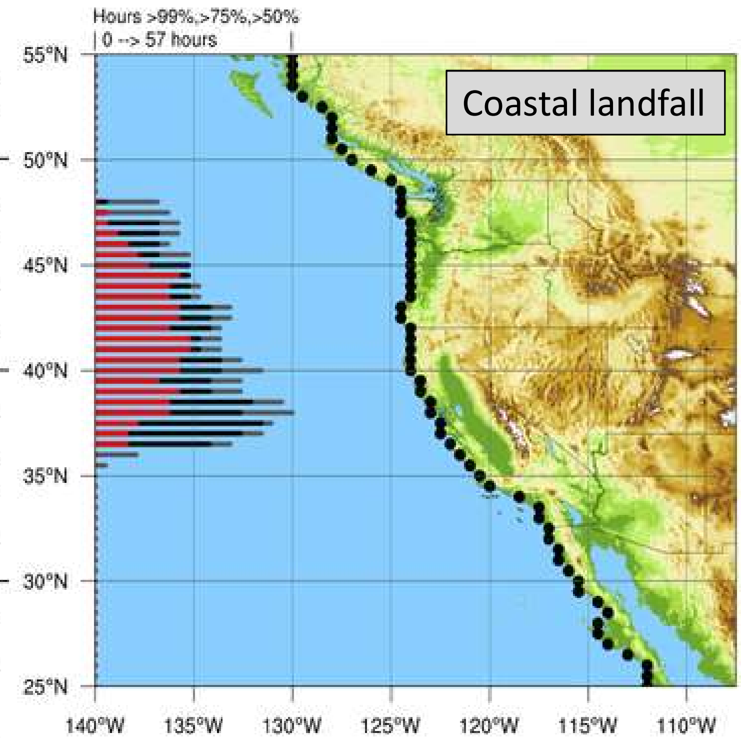


Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

By F. Martin Ralph 2016

AR Landfall and Inland Penetration Probabilities (as of midday Thursday 13 Oct)





Color fill represents the % chance that moderate strength (>500 kg/m/s) atmospheric river will hit at that time and the latitude corresponding to the black dots in the right panels

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

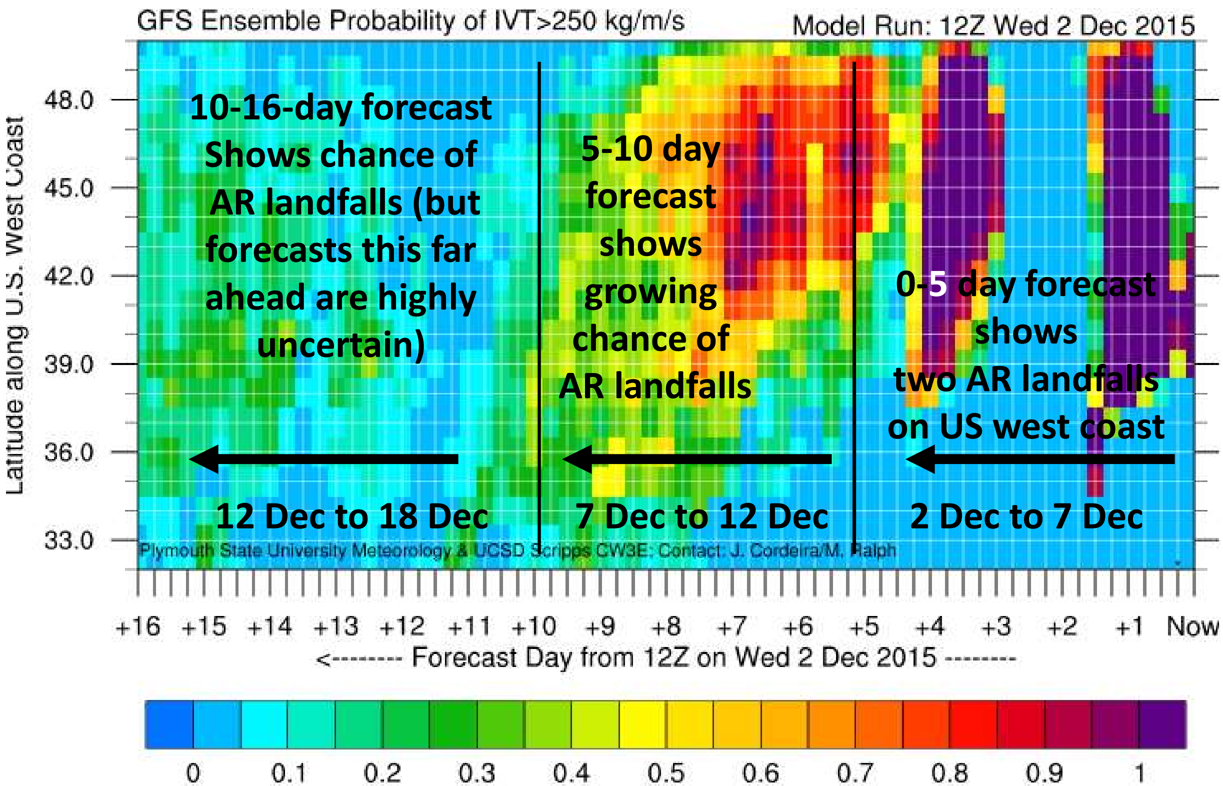
PLYMOUTH STATE METEOROLOGY

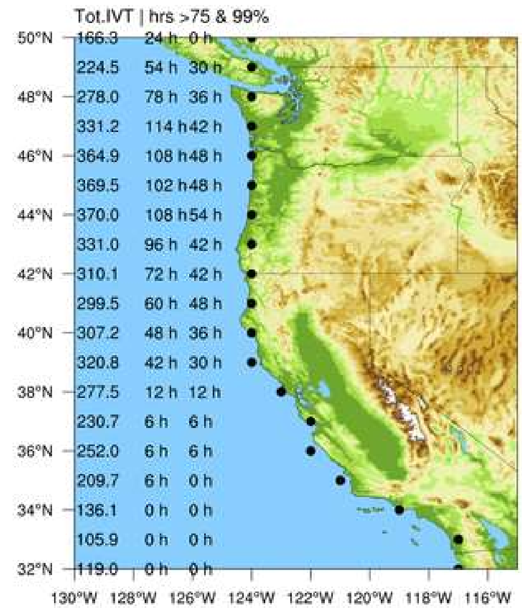
Example of a new AR Forecast Tool: Dec 2014

From J. Cordeira of Plymouth State Univ. and M. Ralph Scripps/CW3E

Available real-time at cw3e.ucsd.edu

Center for Western Weather and Water Extremes





This AR Landfall probability tool is from a partnership between Plymouth State Univ. (Cordeira) and CW3E (Ralph and Kawzenuk)

Forecast chances of landfall of at least WEAK Atmospheric River conditions on the U.S. West Coast from 2-18 Dec 2015 - updates available at cw3e.ucsd.edu *(Cordeira et al. BAMS 2017)*

NCEP GEFS dProg/dt Example from January 2017

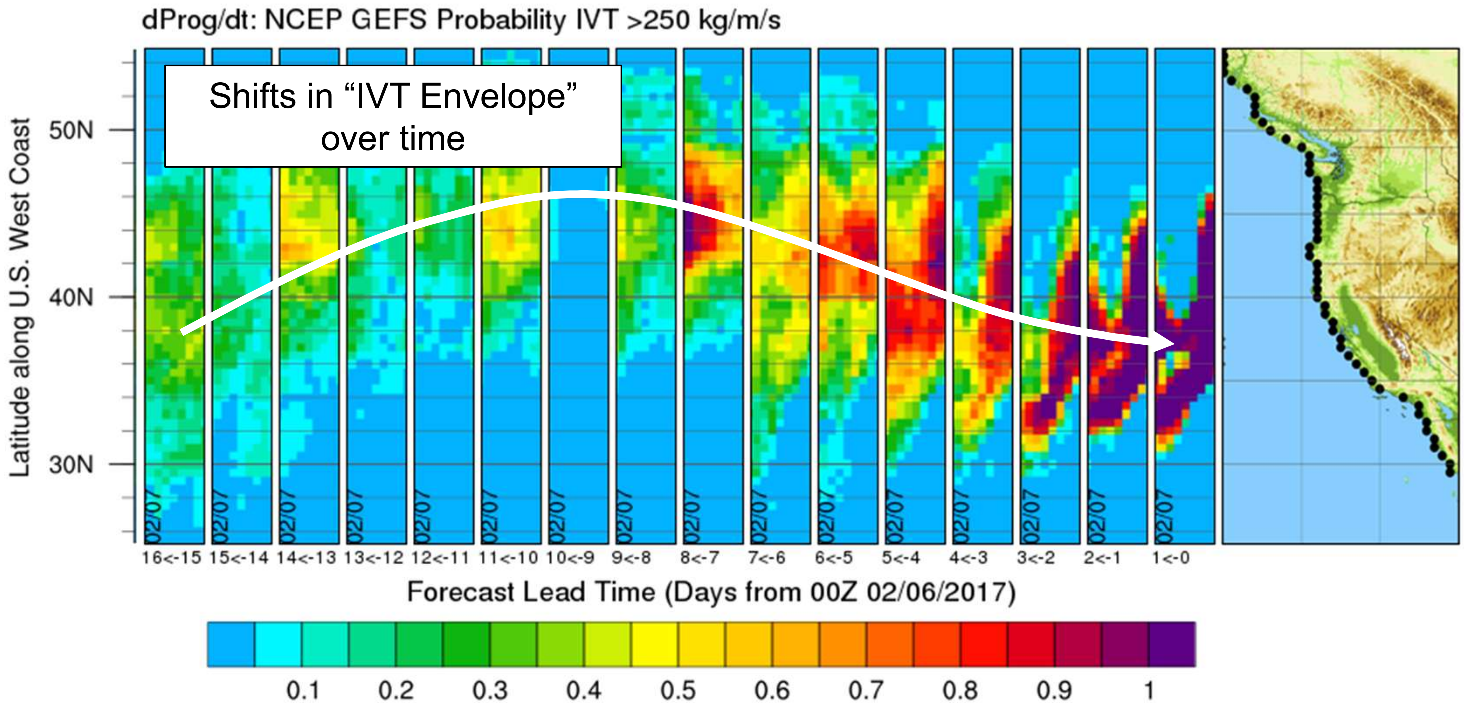
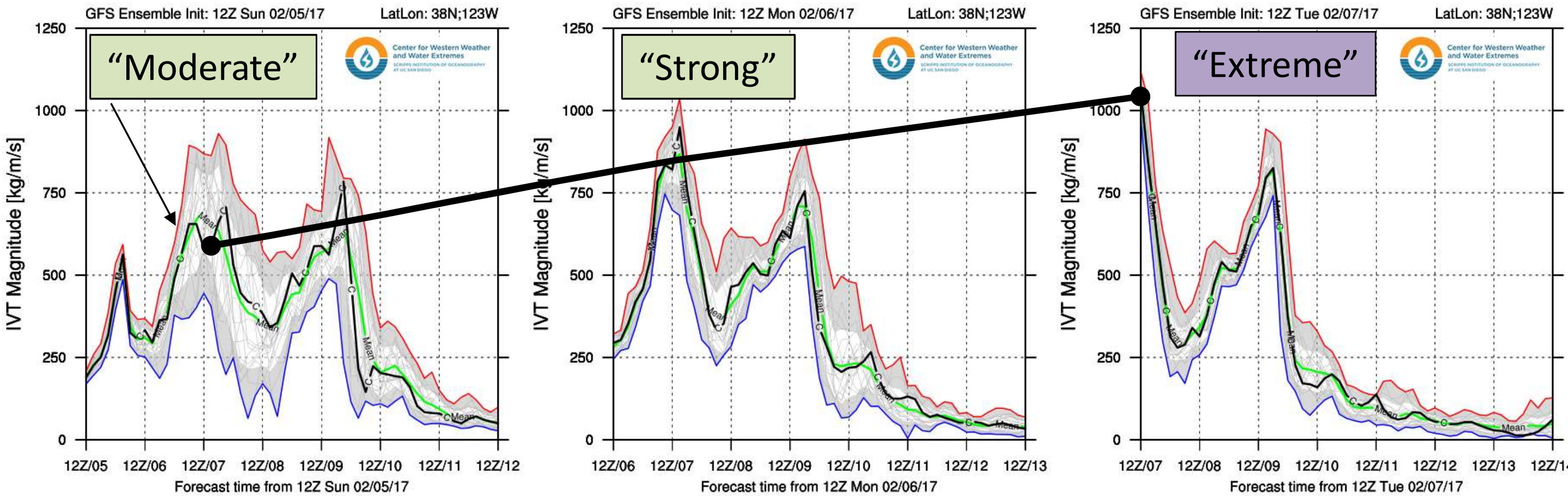


Image Description: Shading represents the NCEP GEFS probability that IVT will exceed 250 kg m^{-1} s^{-1} at 0.5-degree grid locations along the U.S. West Coast (dots). Each panel represents a 24-h forecast that verifies during the 24-h period starting at the time listed above the color bar. The lead time of that forecast period increases from right-to-left. For example, the left-most panel is a 15-to-16-day forecast whereas the right-most panel is the 0-to-1-day forecast.

J. Cordeira

NCEP GEFS dProg/dt Example from February 2017 – “Oroville Case” (dam spillway issue)

Oroville Dam Spillway



Init: 12Z/5 Feb

Init: 12Z/6 Feb

Init: 12Z/7 Feb

Image Description: 7-day forecasts of the NCEP GEFS IVT [kg m^{-1} s^{-1}] at 38N, 123W. The following is indicated at each forecast time: ensemble member maximum (red), ensemble member minimum (blue), ensemble mean (green), ensemble control (black), ensemble standard deviation (white shading), and each individual member (thin gray). Time advances from left to right.

Key: Variability in north-south shift of ARs result in increases or decreases in IVT magnitude at the coast. In this case the ARs ultimately ended up **stronger.**

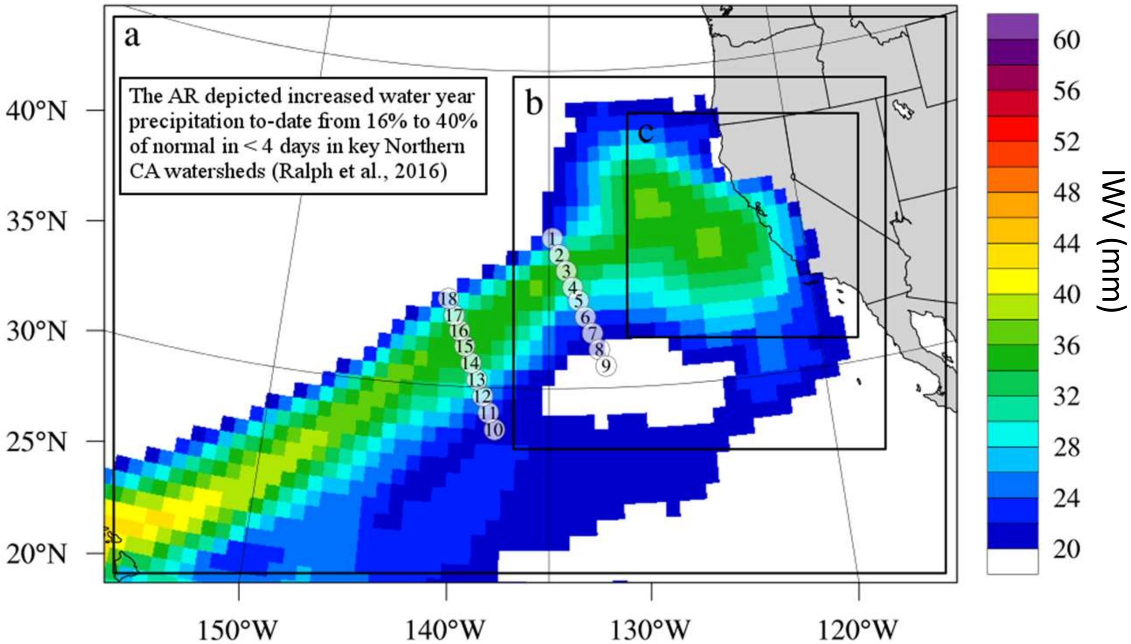
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

F. M. Ralph (mralph@ucsd.edu) and J. Cordeira

SCRIPPS INSTITUTION OF OCEANOGRAPHY UCSD

Evaluation of Atmospheric River Predictions by the WRF Model Using Aircraft and Regional Mesonet Observations of Orographic Precipitation and Its Forcing

Andrew Martin, F Martin Ralph, Reuben Demirdjian, Laurel DeHaan, Rachel Weihs, John Helly, David Reynolds, Sam Iacobellis. *Journal of Hydrometeorology,* https://doi.org/10.1175/JHM-D-17-0098.1



15 aircraft transects of AR were used to measure skill in West-WRF and GFS forecasts.

The data, comprising 191 dropsondes in total, were provided by the CalWater experiments of 2014-2015 (Ralph et al. 2016 *Bull. Amer. Meteor. Soc.)*

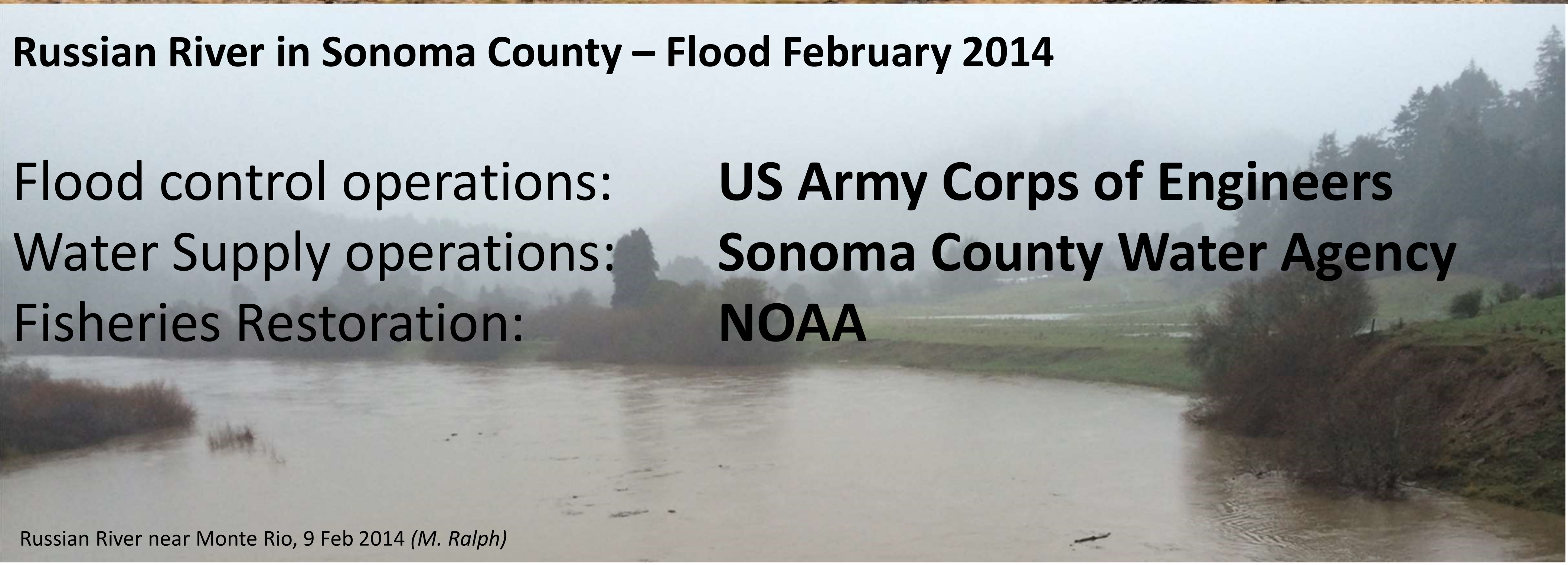
Locations of the Russian River and Lake Mendocino

Lake Mendocino in Sonoma County – Drought July 2014

Lake Mendocino, July 2014

Russian River in Sonoma County – Flood February 2014

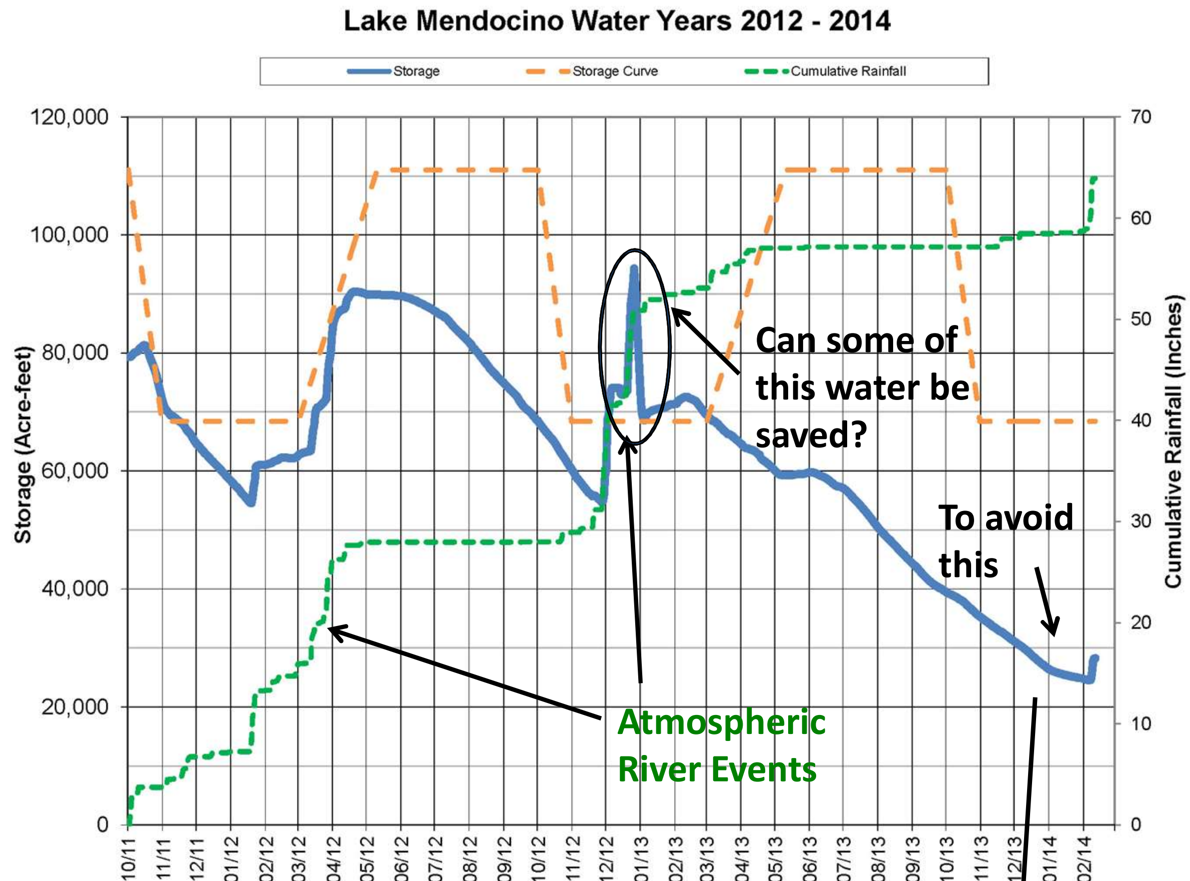
Flood control operations: **US Army Corps of Engineers**
Water Supply operations: **Sonoma County Water Agency**
Fisheries Restoration: **NOAA**



Russian River near Monte Rio, 9 Feb 2014 *(M. Ralph)*

US Army Corps of Engineers and Sonoma County Water Agency manage this reservoir
Flood control, water supply and salmon recovery goals

(a)



Forecast-Informed Reservoir Operations (FIRO)
Project to Assess the Viability of FIRO at Lake Mendo.

(b)

FACT SHEET: Lake Mendocino Forecast Informed Reservoir Operations Preliminary Viability Assessment Work Plan

PURPOSE: The Lake Mendocino Forecast Informed Reservoir Operations (FIRO) Preliminary Viability Assessment Work Plan (Work Plan) describes an approach for using modeling, forecasting tools and improved information to determine whether the Lake Mendocino Water Control Manual can be adjusted to improve flood-control and water supply operations. This proof-of-concept FIRO viability assessment uses Lake Mendocino as a model that could have applicability to other reservoirs.

*STEERING COMMITTEE CO-CHAIRS

Jay Jasperse
Sonoma County Water Agency

F. Martin Ralph
Center for Western Weather and Water Extremes at Scripps Institute of Oceanography

STEERING COMMITTEE MEMBERS

Michael Anderson
California State Climate Office, Department of Water Resources

Levi Brekke
Bureau of Reclamation

Mike Dillabough
US Army Corps of Engineers

Michael Dettinger
United States Geological Survey

Rob Hartman
NOAA's National Weather Service

Christy Jones
US Army Corps of Engineers

Patrick Rutten
NOAA Restoration Center

Cary Talbot
US Army Corps of Engineers

Robert Webb
NOAA's Earth System Research Laboratory

SUPPORT STAFF

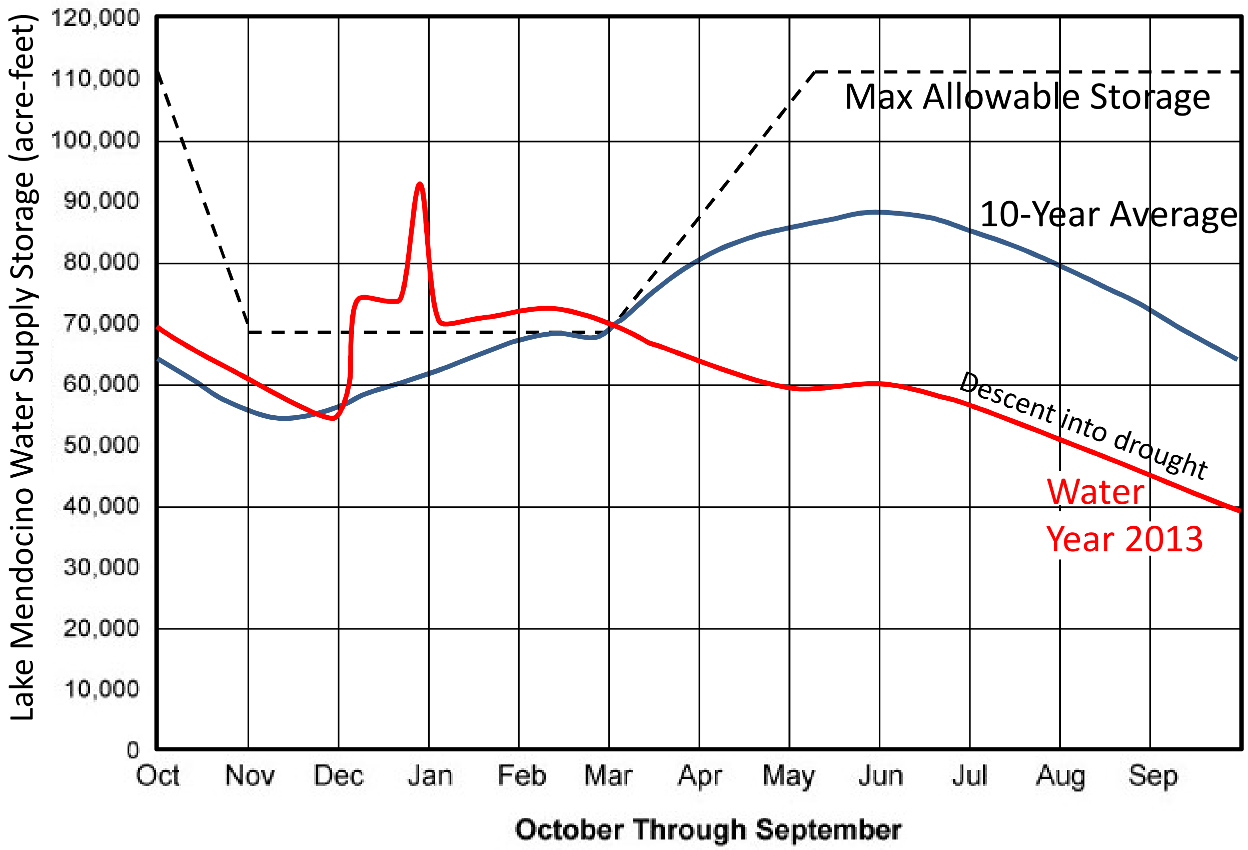
David Ford
David Ford Consulting Engineers

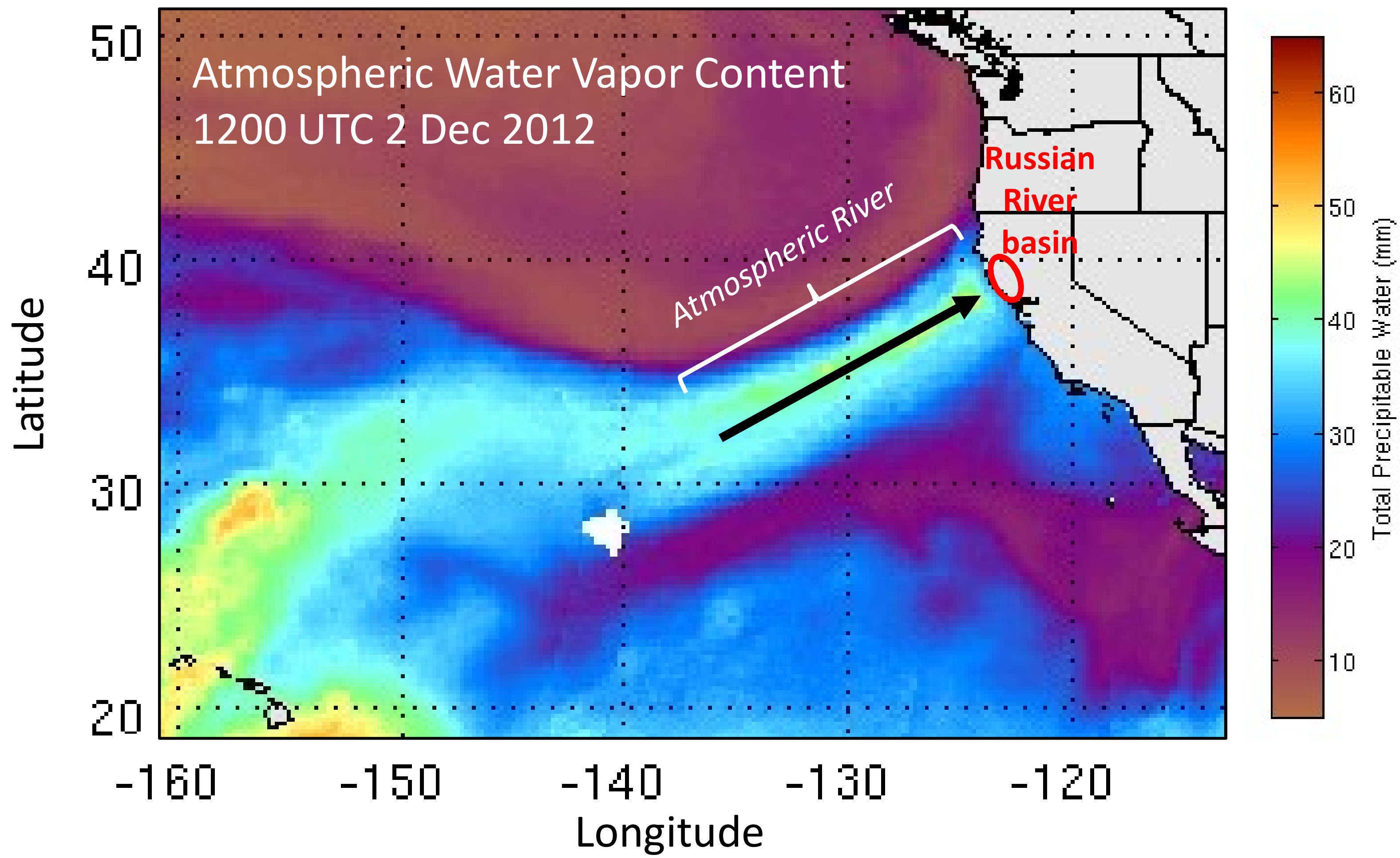
Arleen O'Donnell
Eastern Resarch Group

Ann DuBay
Sonoma County Water Agency

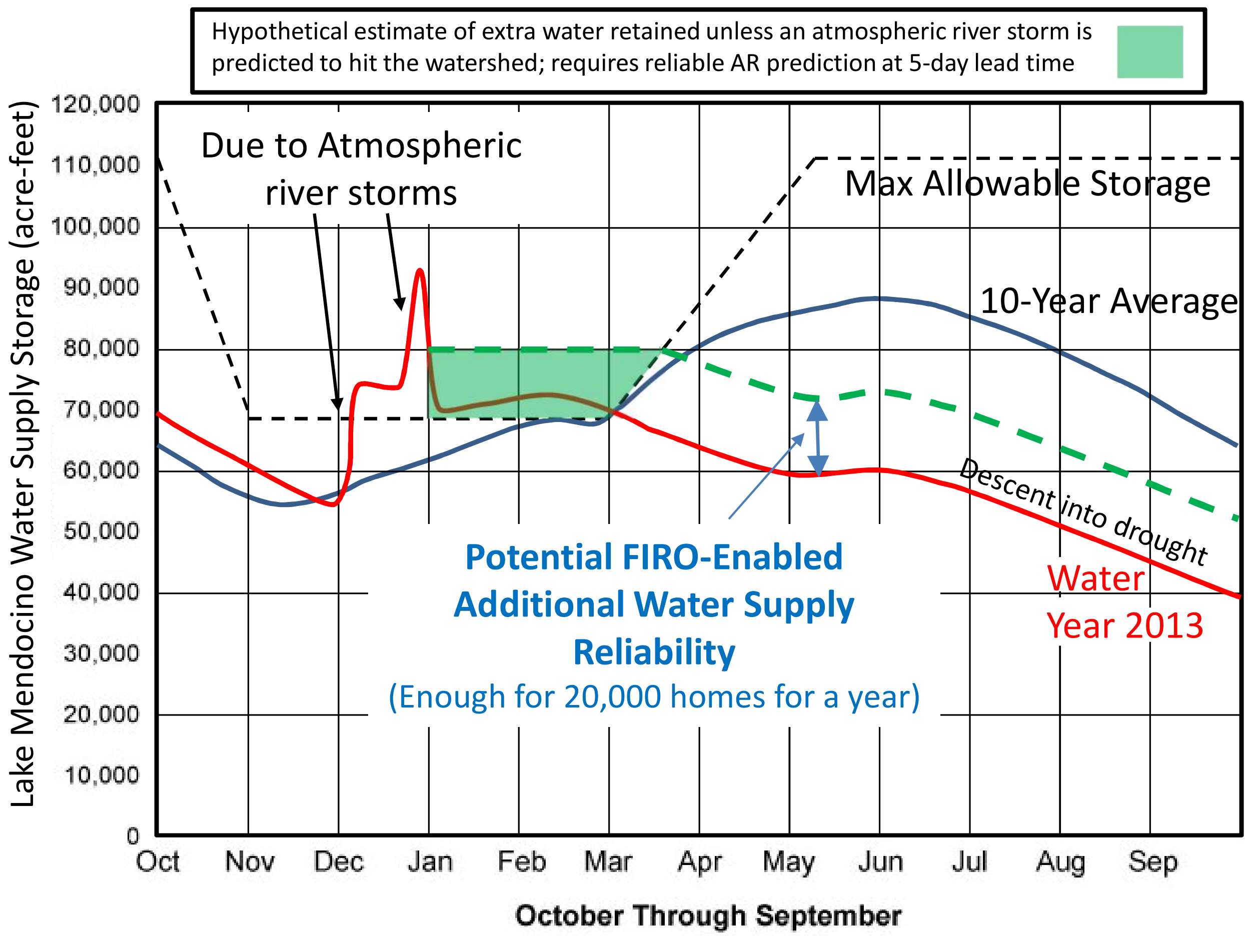
September 2015

Lake Mendocino Forecast-Informed Reservoir Operations Concept




Atmospheric Water Vapor Content
1200 UTC 2 Dec 2012
Atmospheric River
Russian River basin
Latitude
Longitude
50
40
30
20
-160
-150
-140
-130
-120
Total Precipitable Water (mm)
60
50
40
30
20
10

Lake Mendocino Forecast-Informed Reservoir Operations Concept



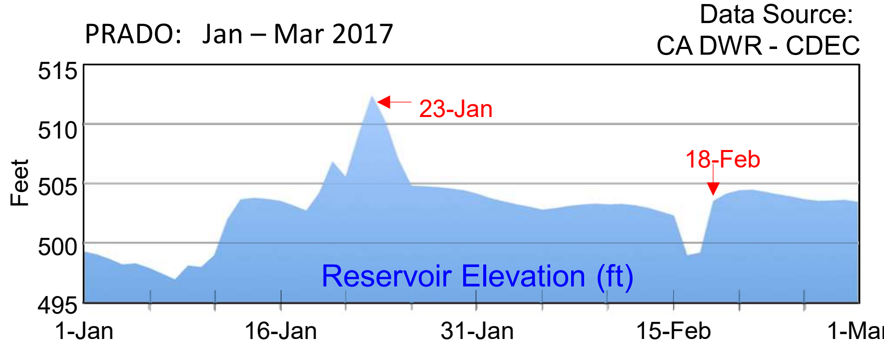
Atmospheric Rivers and Forecast Informed Reservoir Operations at Prado Dam

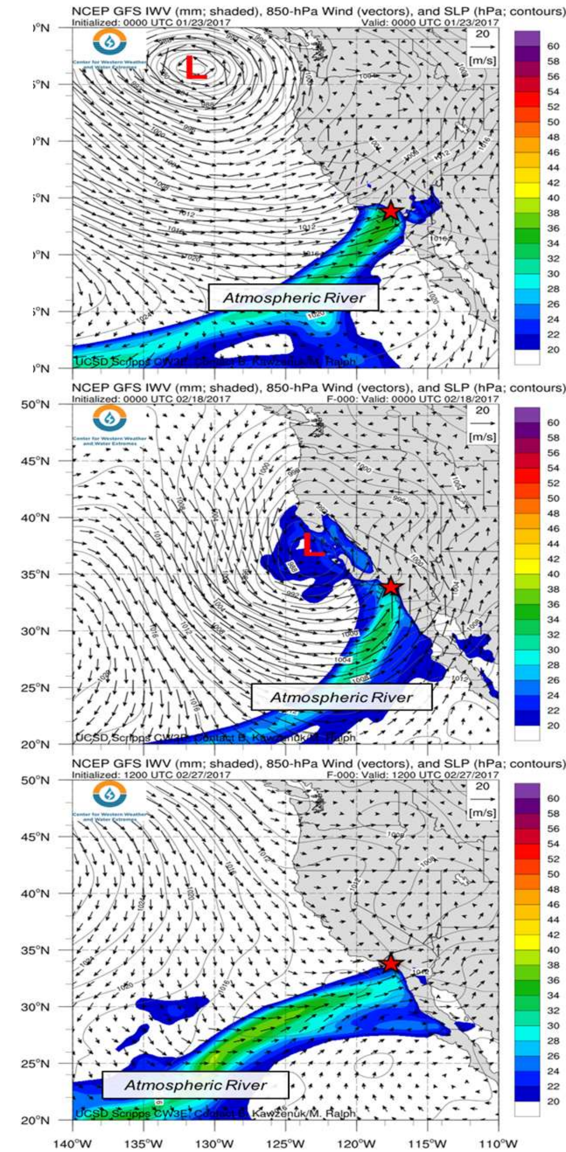
F. Martin Ralph
Center for Western Weather and Water Extremes, UC San Diego/Scripps Institution of Oceanography

Center for Western Weather and Water Extremes

OCWD Board of Directors Meeting
19 Sept. 2018, Irvine CA

Variation in Atmospheric Rivers That Struck Santa Ana River Watershed in 2017





Large differences in synoptic condiitions

F. Cannon
F.M. Ralph
CW3E

Future Directions

- AR Recon (2016 demo; 2018-19 proposed)

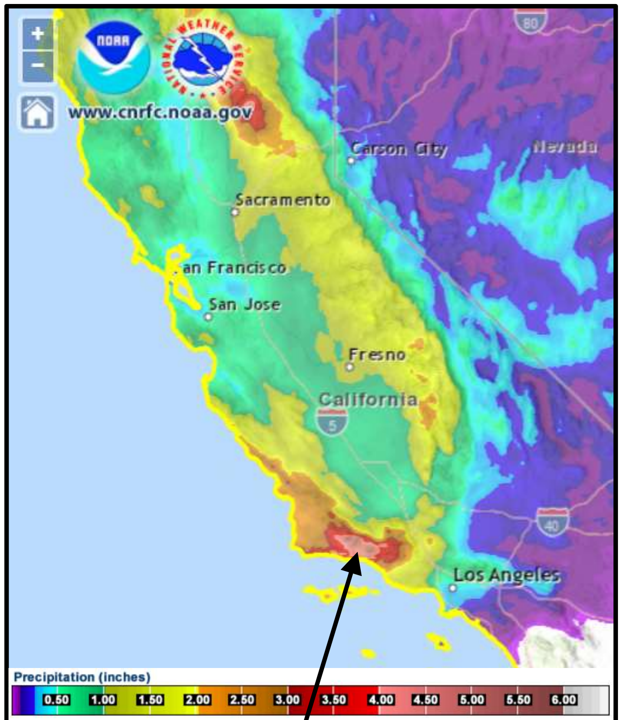
- AR Intensity Scale (focuses on AR instantaneous strength)

- AR Categories (includes AR duration/impacts beneficial vs hazardous)

AR Outlook: 22 March 2018

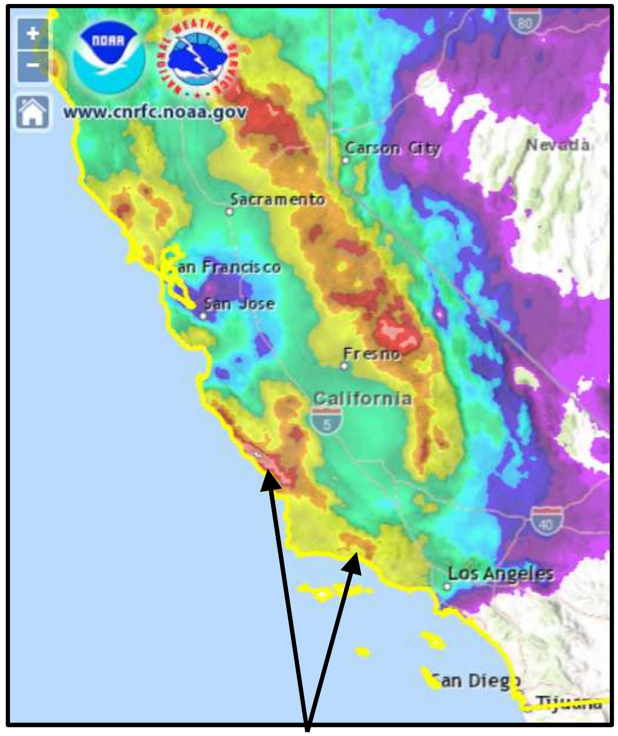
Precipitation Forecast Challenges

CNRFC 24-hr QPF issued 20 March valid 5 AM PDT 21 to 5 AM 22 March 2018

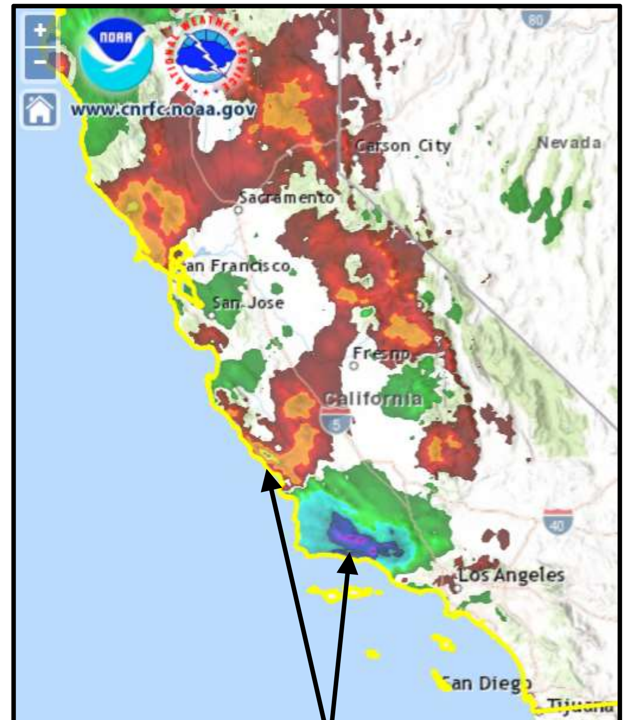


The 24-hr accumulated precipitation forecast for 6”+

CNRFC 24-hr QPE valid 5 AM PDT 21 to 5 AM 22 March 2018

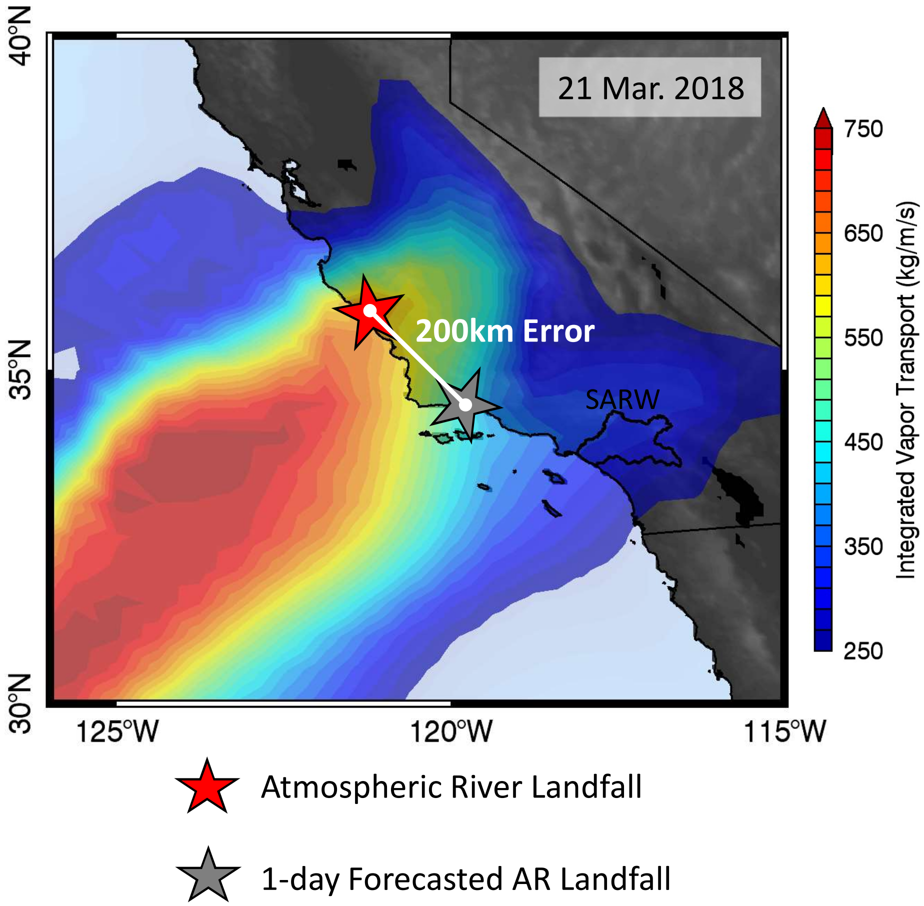


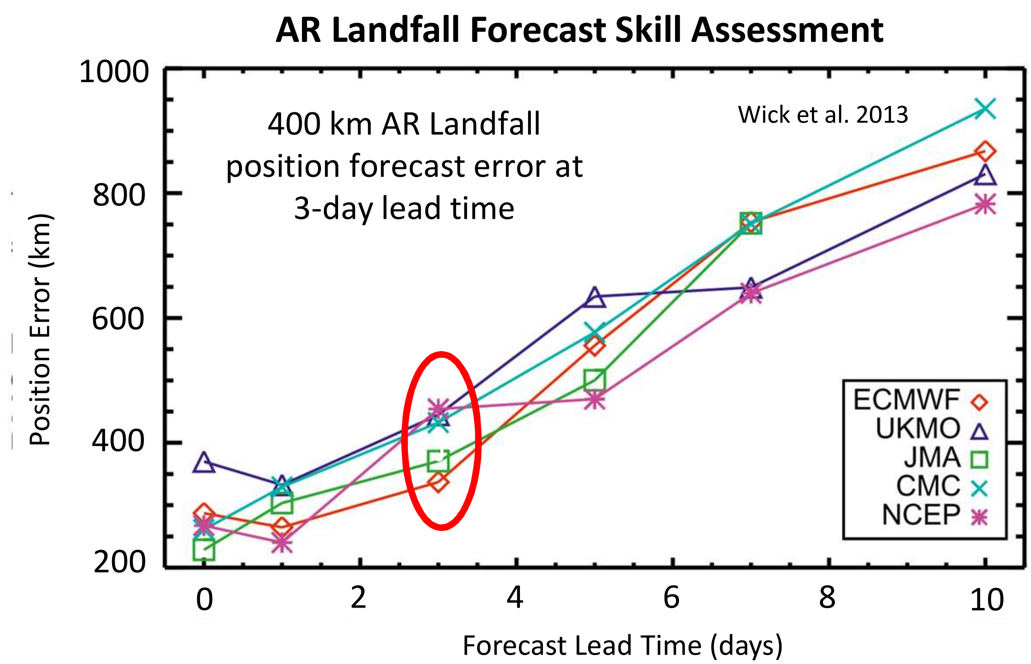
The 24-hr quantitative precipitation estimate (QPE) indicated that ~6” fell along the Coastal Mts. and ~2” fell over the Santa Ynez Mts.



The QPE accumulations resulted in a over forecast of ~4 in. over the Santa Ynez Mts. and an under forecast of ~3 in. over Big Sur

AR Landfall Forecast Challenges

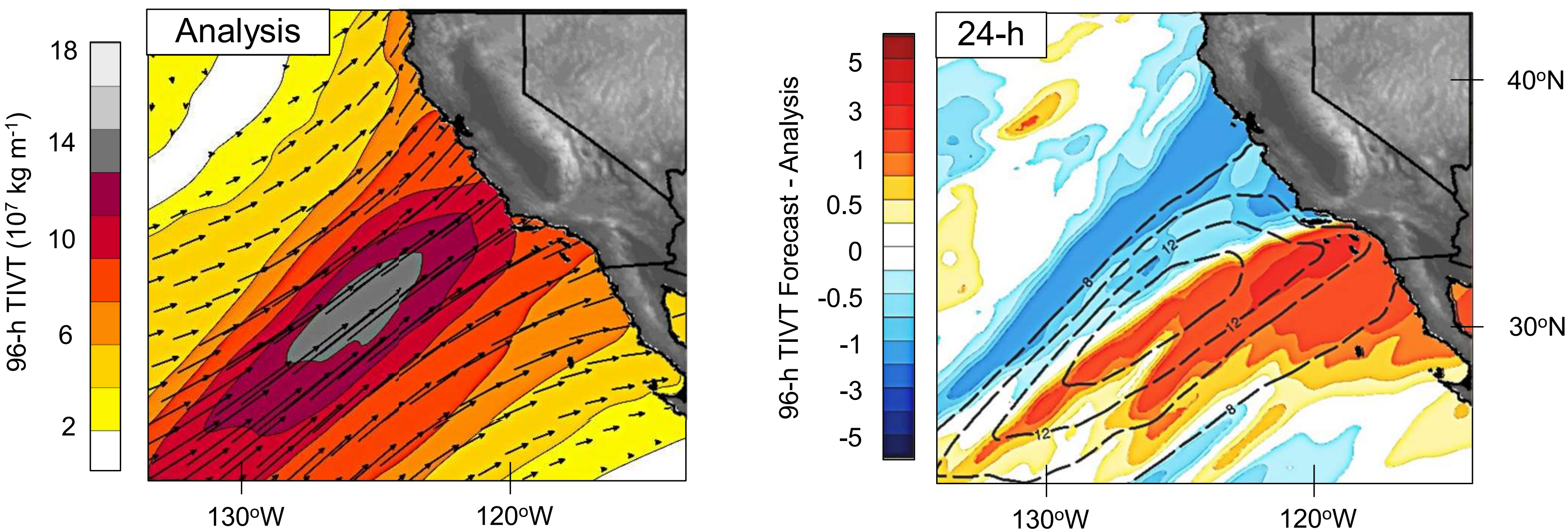




AR Landfall Forecast Challenges

22 March 2018

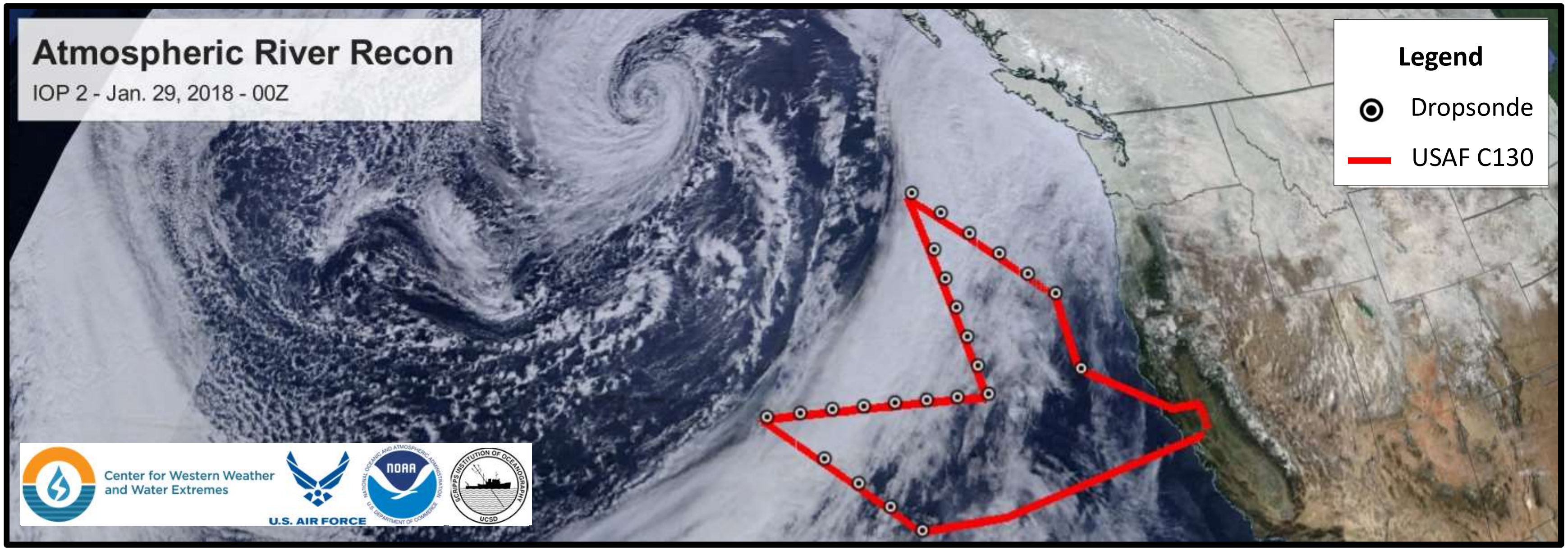
96-h TIVT Analysis and Forecast Verification: Valid 00Z 20 Mar. – 00Z 24 Mar. 2018



- The errors in the precipitation forecasts were partly driven by errors in weather model forecast of AR landfall location
- However, the observations (GFS analysis) showed that the core of the AR was instead over Big Sur (~200-250 km from the predicted position). Big Sur did receive up to 8+ inches of rain, while mountains above Santa Barbara received 2-4 inches

Atmospheric River Reconnaissance

F.M. Ralph, V. Tallapragada, and J. Doyle



Atmospheric River Reconnaissance 2018

6 ARs with up to 3 aircraft per event

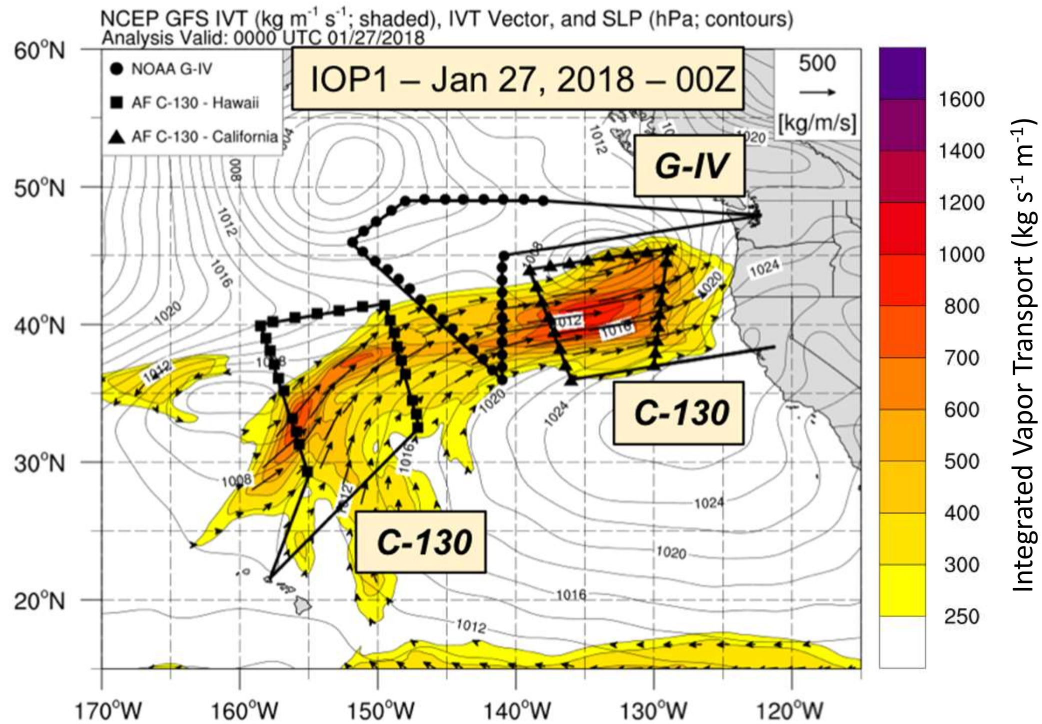
Project Leads

F.M. Ralph (Scripps) - PI
V. Tallapragada (NCEP) - CoPI
J. Doyle (NRL)
C. Davis (NCAR)

Project Support

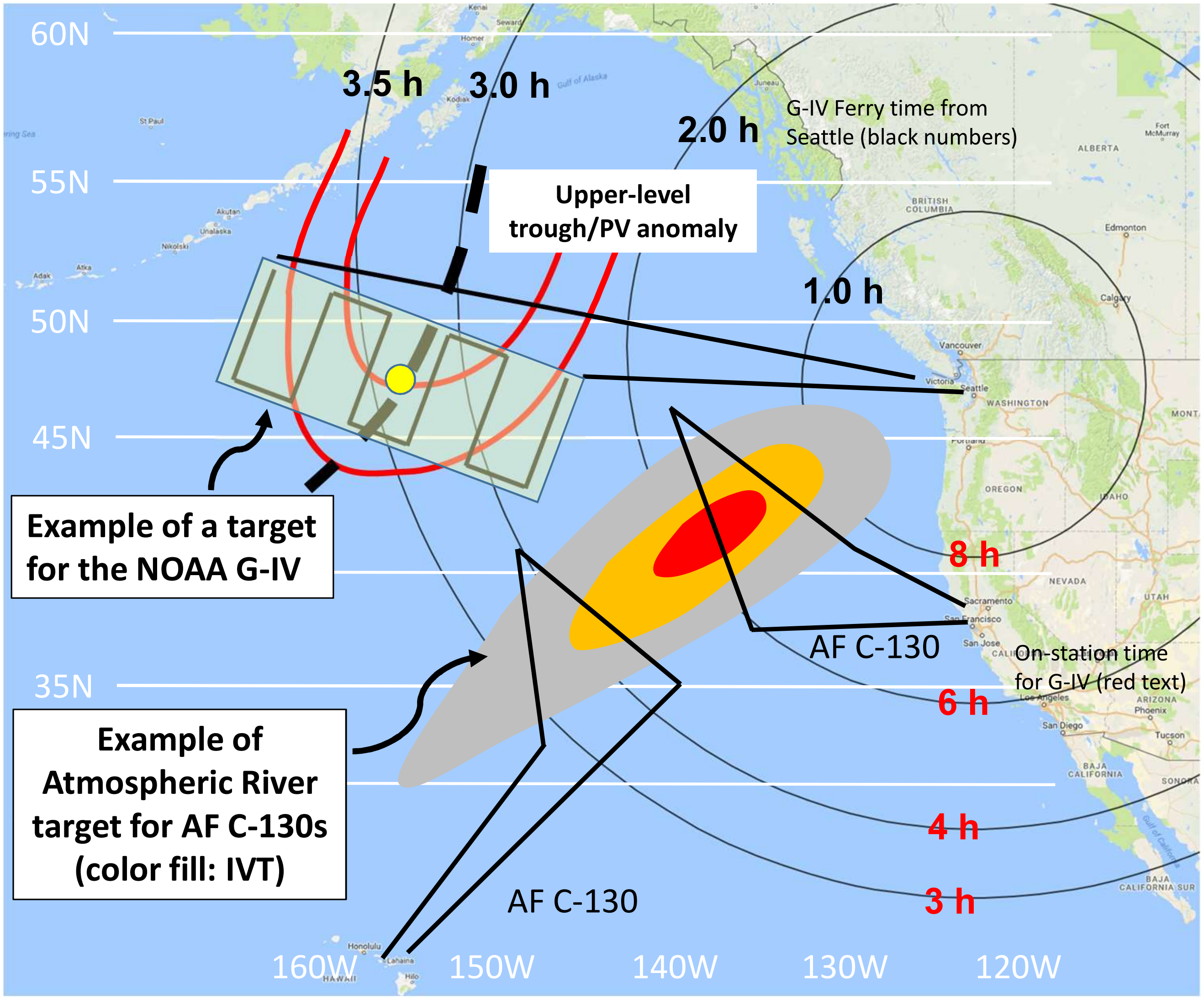
A. Wilson (Scripps)
J. Cordeira (Plymouth St.)
J. Kalansky (Scripps)
F. Cannon (Scripps)
T. Gallarneau (U of Arizona)
L. Bosart (SUNY Albany)
P. Papin (NRL)
C. Hecht (Scripps)
B. Kawzenuk (Scripps)
R. Demirdjian (Scripps)
A. Subramanian (Scripps)
D. Lavers (ECMWF)
F. Pappenberger (ECMWF)
A. Edman (NWS)
J. Rutz (NWS)
A. Lundry (USAF)
J. Parrish (NOAA)

Dropsonde
(temperature, humidity, pressure & winds)



2018
Atmospheric River Reconnaissance Flight Strategies

Center time: 0000 UTC
Dropsonde deployment window:
2100 – 0300 UTC

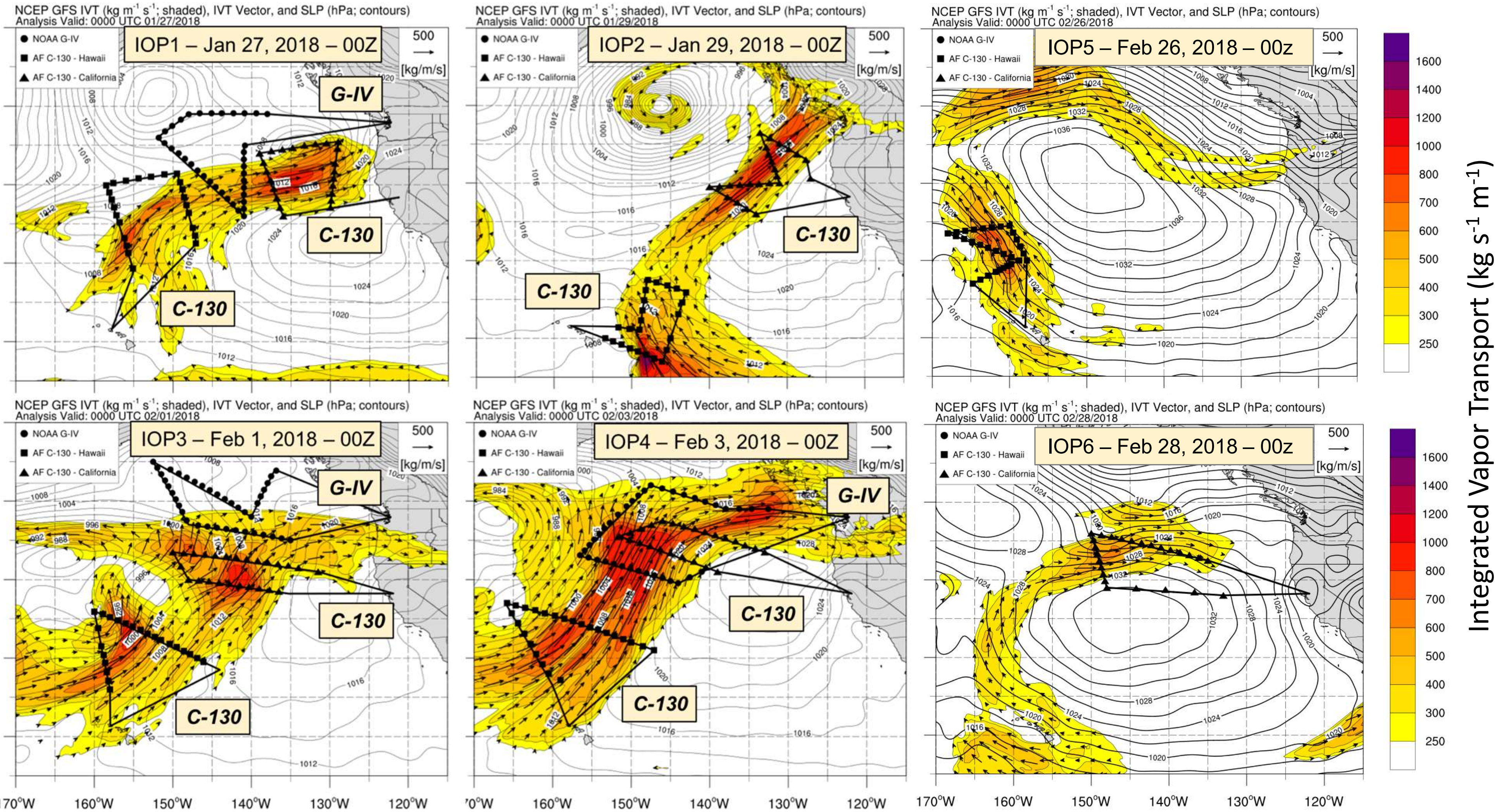


Each aircraft has a range of about 3500 nm

F.M. Ralph (AR Recon PI) and AR Recon Team

Atmospheric River Reconnaissance 2018

Contacts: F. M. Ralph (PI; mralph@ucsd.edu); V. Tallapragada (Co-PI; vijay.tallapragada@noaa.gov)



A Scale to Characterize the Strength and Impacts of Atmospheric Rivers

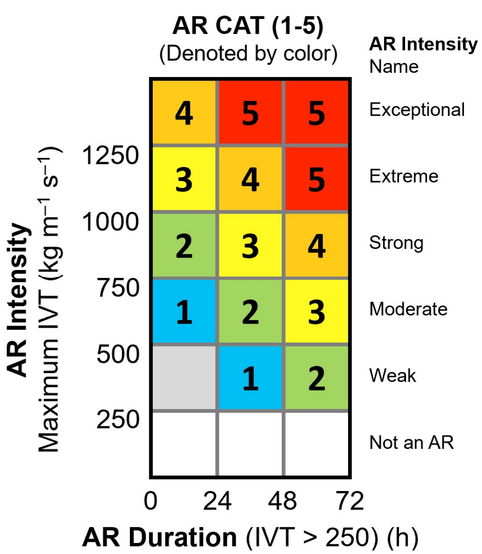
F. Martin Ralph (SIO/CW3E), J. J. Rutz (NWS), J. M. Cordeira (Plymouth State), M. Dettinger (USGS), M. Anderson (CA DWR), D. Reynolds (CIRES), L. Schick (USACE), C. Smallcomb (NWS); *Bull. Amer. Meteor. Soc. (accepted in final form Sept 2018)*

The AR CAT level of an AR Event* is based on its *Duration* and max *Intensity* (IVT)*****

** An "AR Event" refers to the existence of AR conditions at a specific location for a specific period of time.*
*** How long IVT>250 at that location. If duration is <24 h, reduce AR CAT by 1, if longer than 48 h, add 1.*
**** This is the max IVT at the location of interest during the AR.*

IMPACTS

- AR Cat 5 – Primarily hazardous
- AR Cat 4 – Mostly hazardous, also beneficial
- AR Cat 3 – Balance of beneficial and hazardous
- AR Cat 2 – Mostly beneficial, also hazardous
- AR Cat 1 – Primarily beneficial



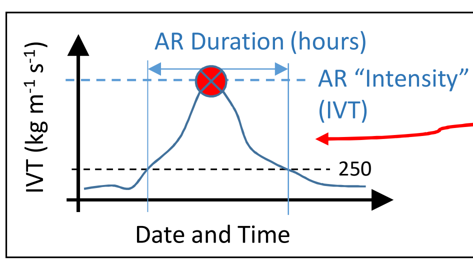
Determining AR Intensity and AR Category

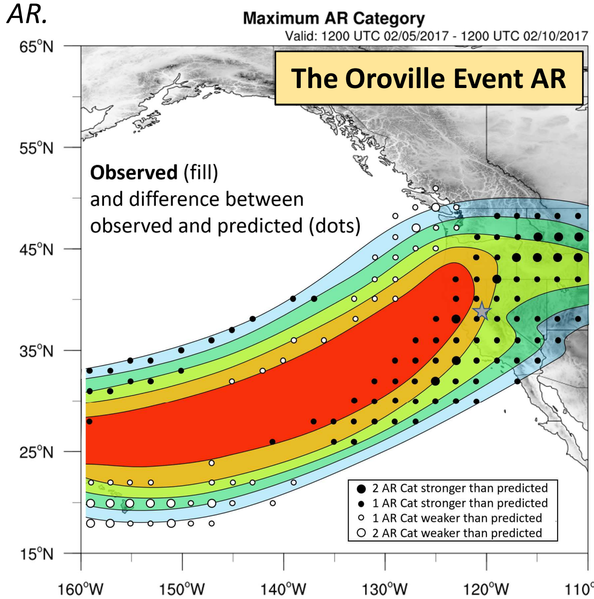
Step 1: Pick a location

Step 2: Determine a time period when IVT > 250 (using 3 hourly data) at that location, either in the past or as a forecast. The period when IVT continuously exceeds 250 determines the start and end times of the AR, and thus also the **AR Duration** for the AR event at that location.

Step 3: Determine **AR Intensity**
- Determine max IVT during the AR at that location
- This sets the AR Intensity and *preliminary* AR CAT

Step 4: Determine *final* value of **AR CAT** to assign
- If the AR Duration is > 48 h, then promote by 1 Category
- If the AR Duration is < 24 h, then demote by 1 Category





On the Web: CW3E.UCSD.EDU
On Twitter: @CW3E_Scripps

Center for Western Weather and Water Extremes

"Atomspheric River" drink created for season at Harrah's and Harveys

Submitted by paula on Wed, 02/22/2017 - 1:55pm

Rivers have flooded, the lake is filling and snow is covering the slopes because of the several atmospheric rivers to hit Lake Tahoe this winter. To celebrate the epic season, the Beverage Department team at Harrah's and Harveys Lake Tahoe concocted a cocktail to honor and celebrate the winter.

The "Atmospheric River" drink "blends the frosty peaks of the Sierra Nevada with the stunning shades of blue found only at Lake Tahoe," said John Packer of Harrah's and Harveys Lake Tahoe.

Named for the climatic condition that has held sway in northern California and Nevada for the past few months, the "Atmospheric River" combines fruit juices, vodka, cognac and other ingredients to produce one of the most refreshing adult beverages of the season.

The festive cocktail is available exclusively at the two California Bars, located on the main floor of both casinos in Stateline, Nevada.

Their master mixologists combine Grey Goose Vodka, Hpnotiq Liqueur, Cointreau, Curacao, Sweet and Sour with Seven-Up, blend it with ice and serve it up in a chilled, sugar-rimmed martini glass.

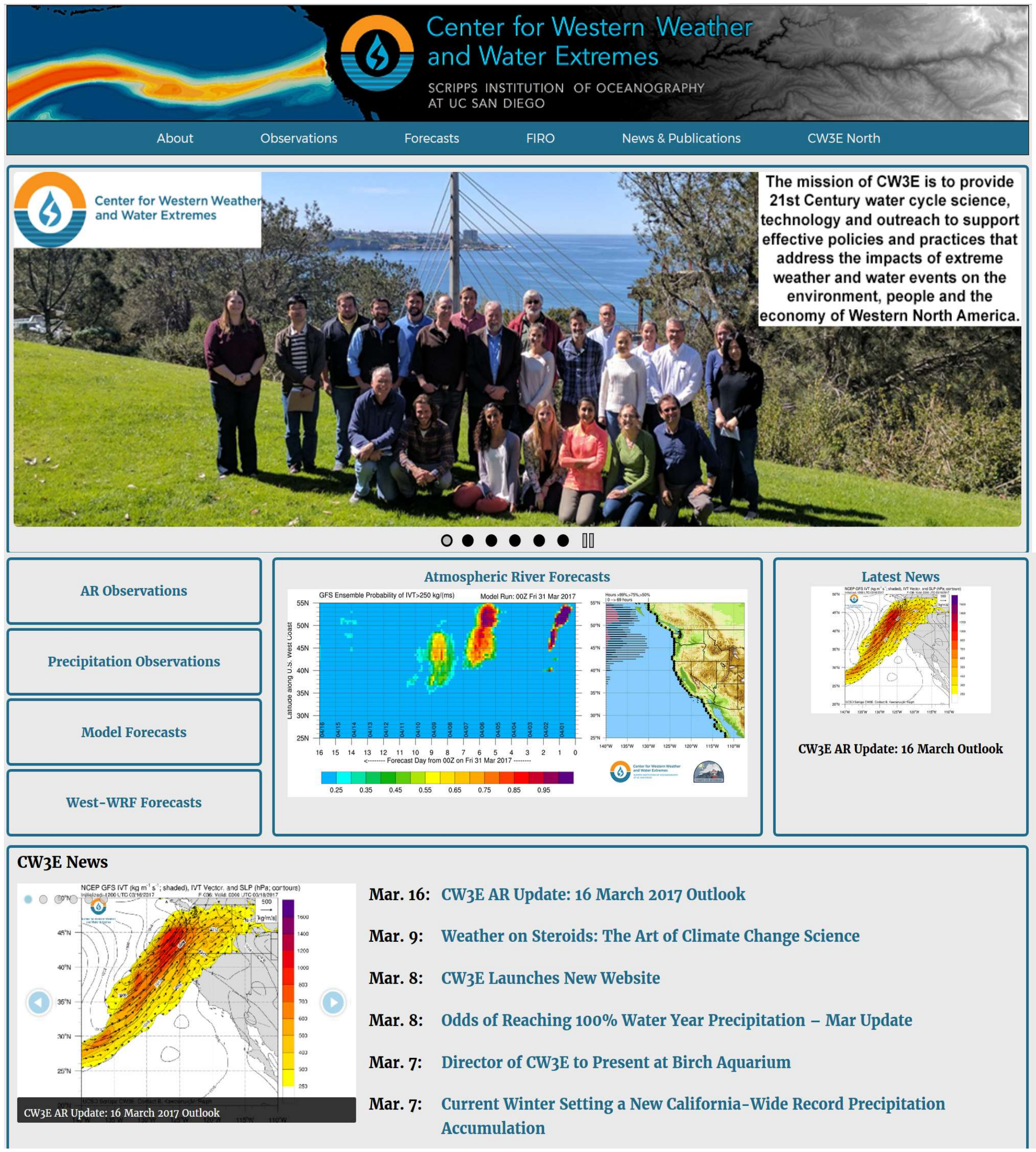
It's a "drought-busting libation."

Tweets   Tweets & replies   Media

South Tahoe Now @SouthTahoeNow · 10m

Atmospheric River cocktail created @HarrahsTahoe and @harveystahoe to celebrate extra wet & snowy season #LakeTahoe southtahoenow.com/story/02/22/20…

1 oz Grey Goose Vodka + 1 oz Hpnotiq Liquer + 1 oz Cointreau, top off with Sweet and Sour with 7-Up; blend with ice and serve in sugar-rimmed, chilled martini glass.



AR Forecast Tools

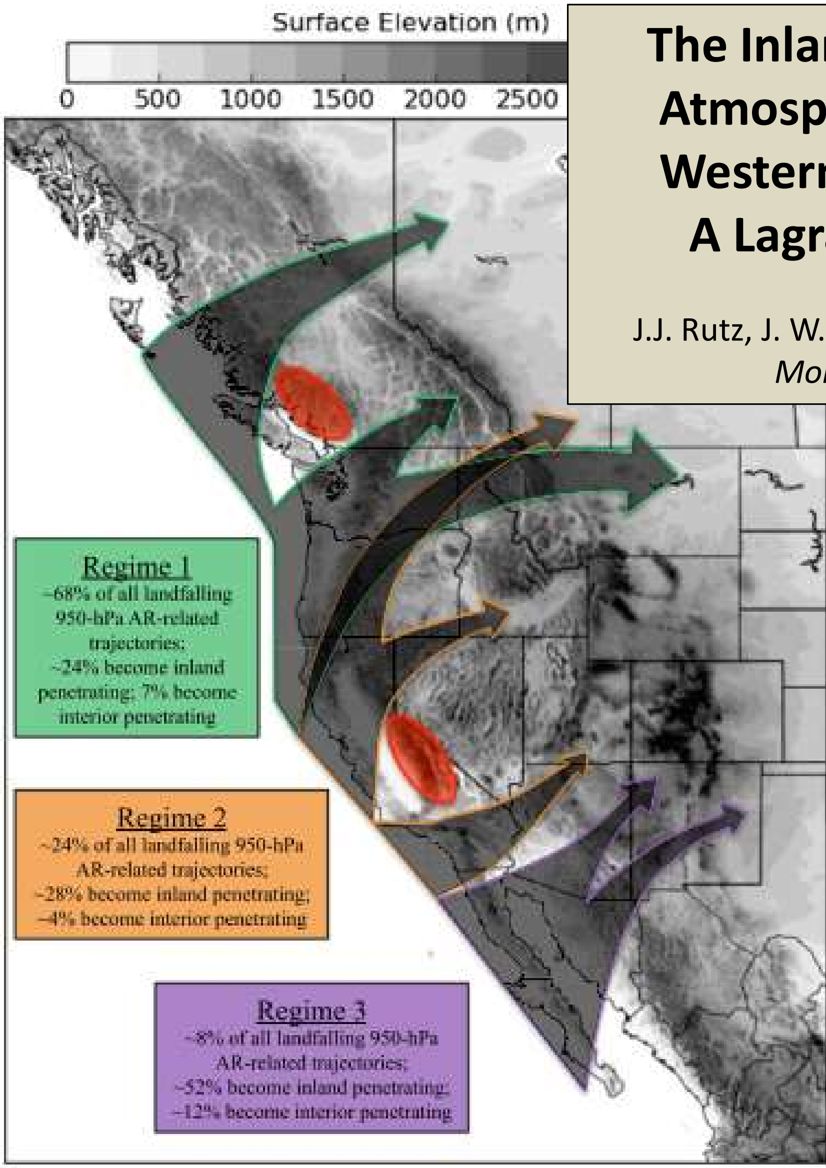
Extreme Event Summaries

Lake Mendocino FIRO summary information

Are available at

CW3E.UCSD.EDU

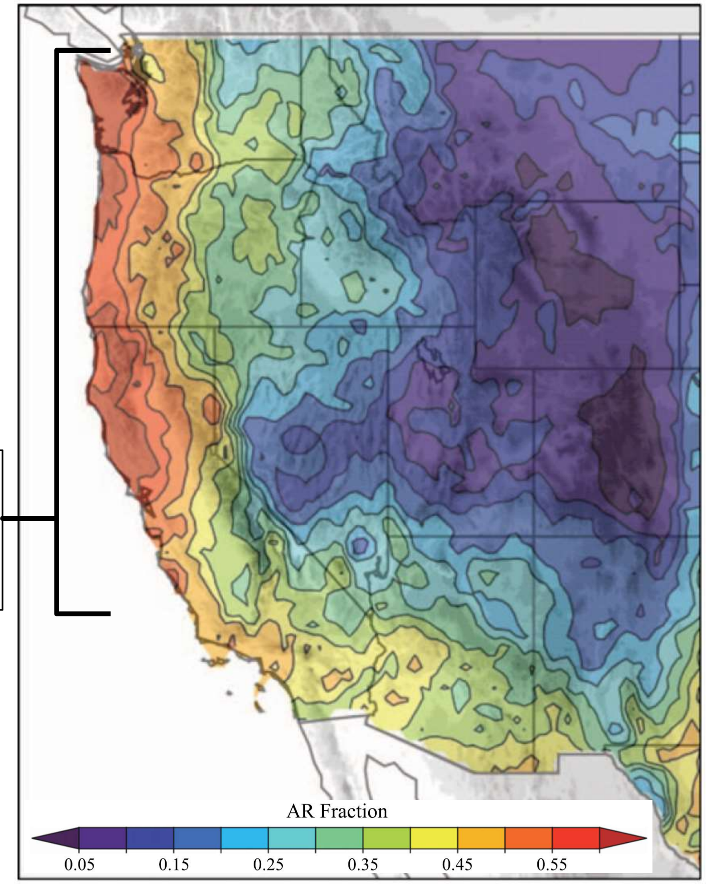
Contact: mralph@ucsd.edu



The Inland Penetration of Atmospheric Rivers over Western North America: A Lagrangian Analysis

J.J. Rutz, J. W. Steenburgh and F.M. Ralph
Mon. Wea. Rev., 2015

40-50% of annual precipitation falls during AR events in key areas



Climatological Characteristics of Atmospheric Rivers and Their Inland Penetration over the Western United States

J.J. Rutz, J. W. Steenburgh and F.M. Ralph
Mon. Wea. Rev., 2014

R-Cat Precipitation Scale: 3-day total rainfall

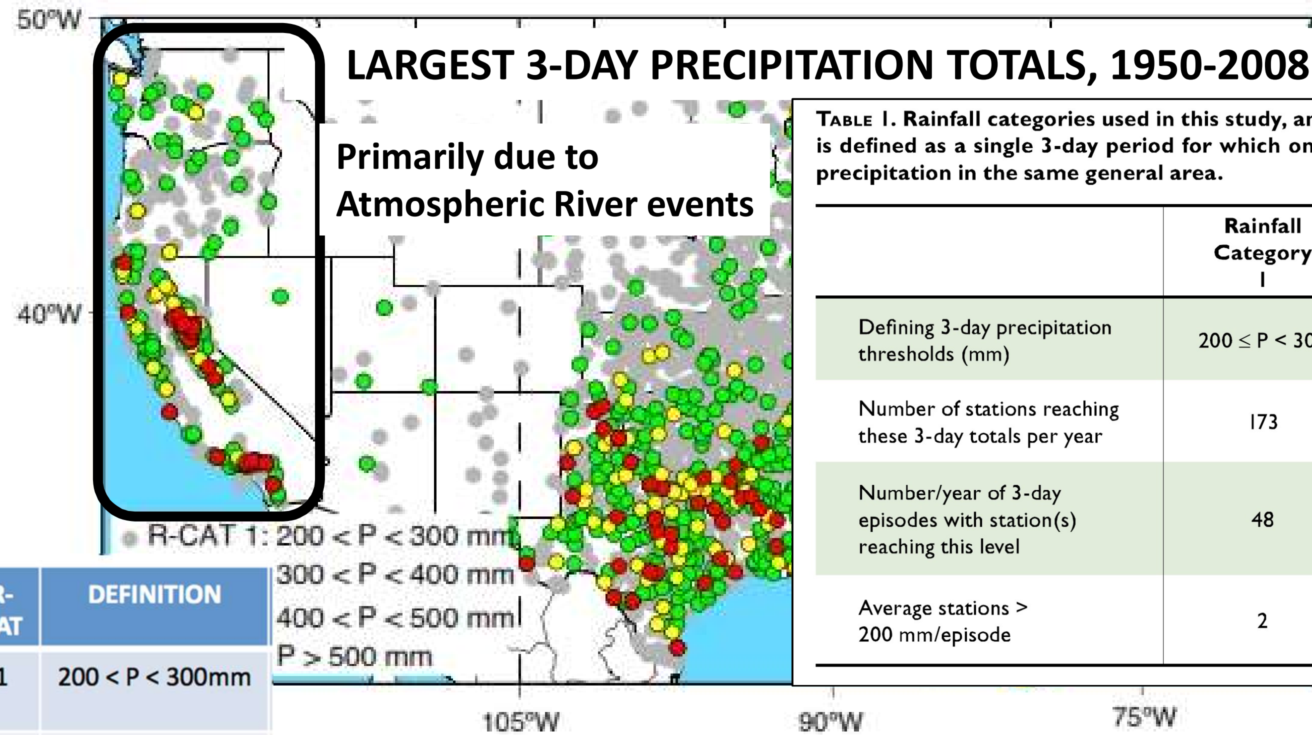


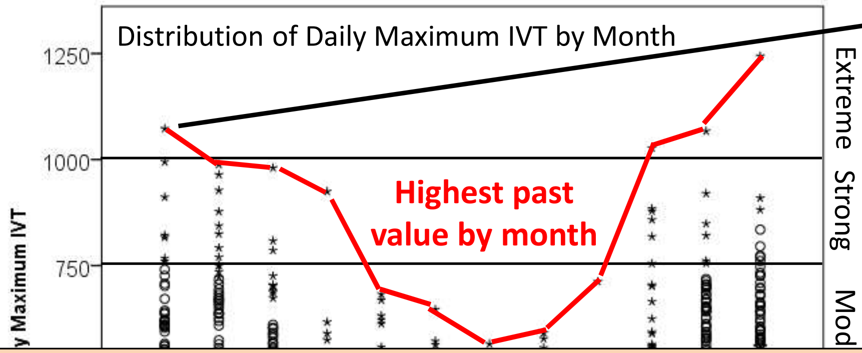
Table 1. Rainfall categories used in this study, and national frequencies of occurrence. Note that an "episode" is defined as a single 3-day period for which one or more stations observed at least 200 mm (~ 8 inches) of precipitation in the same general area.

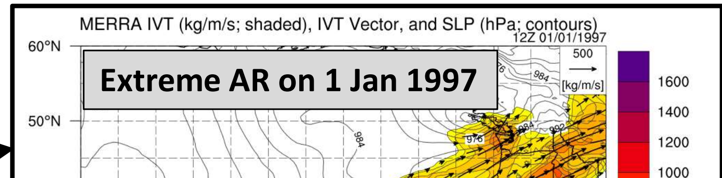
	Rainfall Category 1	Rainfall Category 2	Rainfall Category 3	Rainfall Category 4
Defining 3-day precipitation thresholds (mm)	200 ≤ P < 300	300 ≤ P < 400	400 ≤ P < 500	500 ≥ P
Number of stations reaching these 3-day totals per year	173	23	4	2
Number/year of 3-day episodes with station(s) reaching this level	48	9	2	1
Average stations > 200 mm/episode	2	7	13	15

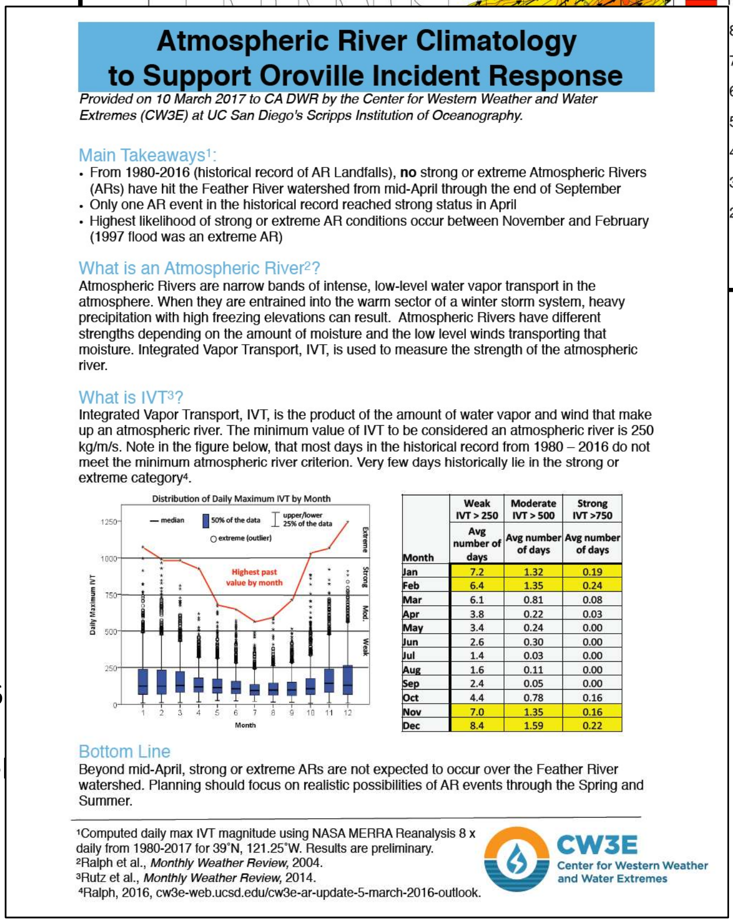
R-CAT	DEFINITION
1	200 < P < 300mm
2	300 < P < 400mm
3	400 < P < 500mm
4	P > 500mm

Ralph, F.M., and Dettinger, M.D. 2012, Historical and national perspectives on extreme west-coast precipitation associated with atmospheric rivers during December 2010: *Bulletin of the American Meteorological Society,* (2012)

From mid April to September no “strong” or “extreme” ARs hit Oroville area
(Based on the period from 1980-2016 when the necessary data are available)







Atmospheric River Climatology to Support Oroville Incident Response

Provided on 10 March 2017 to CA DWR by the Center for Western Weather and Water Extremes (CW3E) at UC San Diego's Scripps Institution of Oceanography.

Main Takeaways[1]:

- From 1980-2016 (historical record of AR Landfalls), **no** strong or extreme Atmospheric Rivers (ARs) have hit the Feather River watershed from mid-April through the end of September
- Only one AR event in the historical record reached strong status in April
- Highest likelihood of strong or extreme AR conditions occur between November and February (1997 flood was an extreme AR)

What is an Atmospheric River[2]?

Atmospheric Rivers are narrow bands of intense, low-level water vapor transport in the atmosphere. When they are entrained into the warm sector of a winter storm system, heavy precipitation with high freezing elevations can result. Atmospheric Rivers have different strengths depending on the amount of moisture and the low level winds transporting that moisture. Integrated Vapor Transport, IVT, is used to measure the strength of the atmospheric river.

What is IVT[3]?

Integrated Vapor Transport, IVT, is the product of the amount of water vapor and wind that make up an atmospheric river. The minimum value of IVT to be considered an atmospheric river is 250 kg/m/s. Note in the figure below, that most days in the historical record from 1980 – 2016 do not meet the minimum atmospheric river criterion. Very few days historically lie in the strong or extreme category[4].

Month	Weak IVT > 250	Moderate IVT > 500	Strong IVT >750
	Avg number of days	Avg number of days	Avg number of days
Jan	7.2	1.32	0.19
Feb	6.4	1.35	0.24
Mar	6.1	0.81	0.08
Apr	3.8	0.22	0.03
May	3.4	0.24	0.00
Jun	2.6	0.30	0.00
Jul	1.4	0.03	0.00
Aug	1.6	0.11	0.00
Sep	2.4	0.05	0.00
Oct	4.4	0.78	0.16
Nov	7.0	1.35	0.16
Dec	8.4	1.59	0.22

Bottom Line

Beyond mid-April, strong or extreme ARs are not expected to occur over the Feather River watershed. Planning should focus on realistic possibilities of AR events through the Spring and Summer.

[1]Computed daily max IVT magnitude using NASA MERRA Reanalysis 8 x daily from 1980-2017 for 39°N, 121.25°W. Results are preliminary.
[2]Ralph et al., *Monthly Weather Review*, 2004.
[3]Rutz et al., *Monthly Weather Review*, 2014.
[4]Ralph, 2016, cw3e-web.ucsd.edu/cw3e-ar-update-5-march-2016-outlook.

CW3E Center for Western Weather and Water Extremes

From mid April to September no “strong” or “extreme” ARs hit Oroville area from 1980-2016

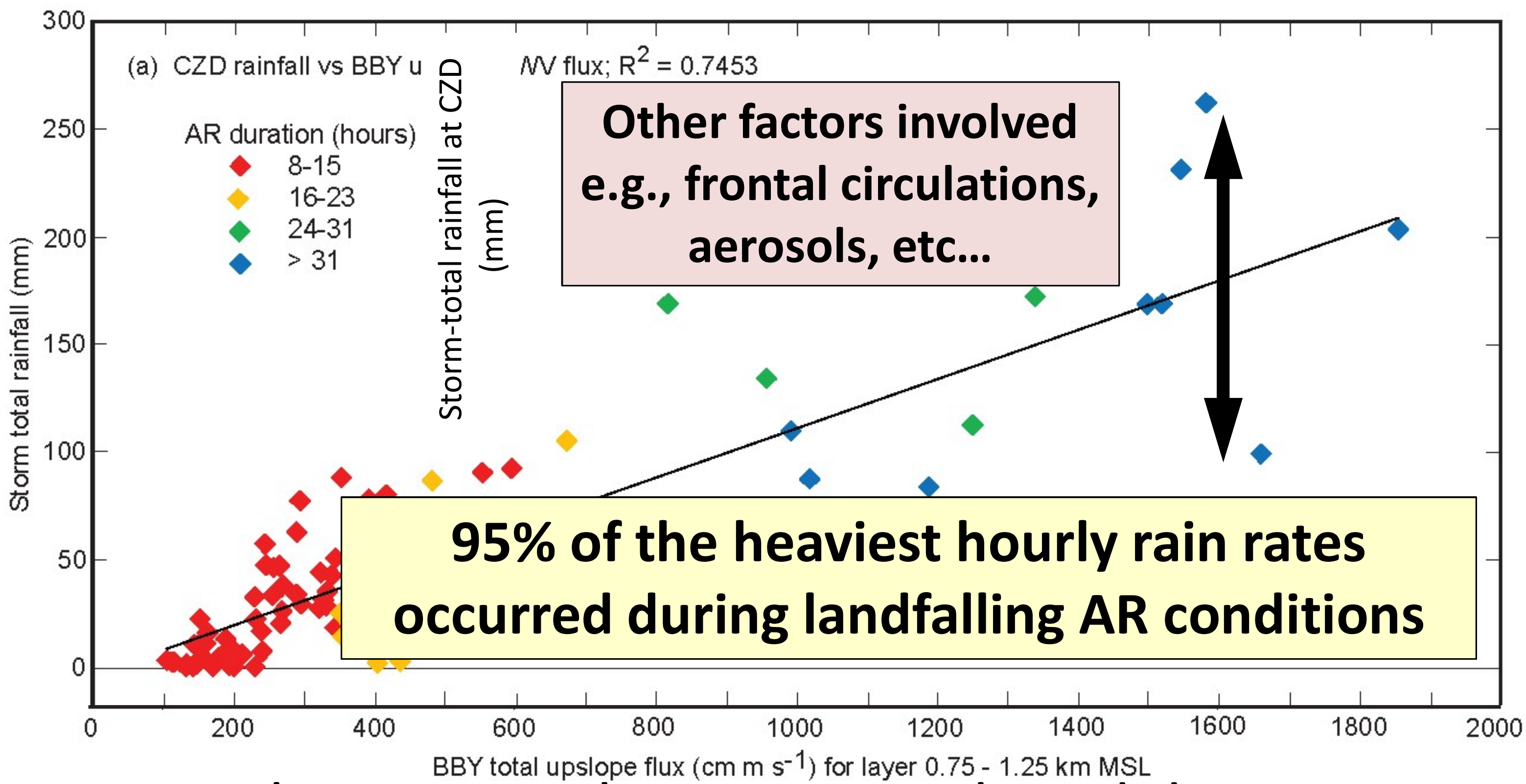
Box plot analysis of the monthly distribution of all inclusive daily maximum IVT magnitudes: 1980–2016
Main Takeaways

- Highest likelihood of strong (or extreme) IVT magnitudes >750 (1000) kg/m/s occur during Nov – Fe
- Only one day during April had “strong” IVT magnitude of 750–1000 kg/m/s
- From mid April to September no “strong” or “extreme” ARs hit Oroville area from 1980-2016

Provided to DWR by F.M. Ralph, J. Cordeira, C. Hecht, B. Kawzenuk, 10 March 2017

Observed impacts of duration and seasonality of atmospheric-river landfalls on soil moisture and runoff in coastal northern California

Ralph, F. M., T. Coleman, P.J. Neiman, R. Zamora, and M.D. Dettinger, J. Hydrometeorology, 2013



The greater the AR strength and duration

The greater the precipitation

CalWater Field Studies Designed to Quantify the Roles of Atmospheric Rivers and Aerosols in Modulating U.S. West Coast Precipitation in a Changing Climate

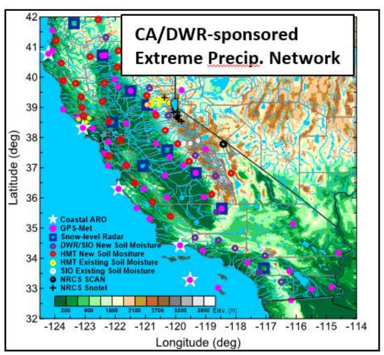
Ralph F.M., K. A. Prather, D. Cayan, J.R. Spackman, P. DeMott, M. Dettinger, C. Fairall, R. Leung, D. Rosenfeld, S. Rutledge, D. Waliser, A. B. White, J. Cordeira, A. Martin, J. Helly, and J. Intrieri, 2016, ***Bull. Amer. Meteor. Soc.***

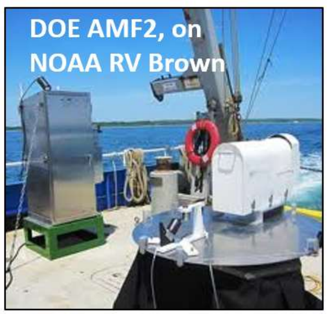
“CalWater – 2015” Field Experiment on Atmospheric Rivers & Aerosols

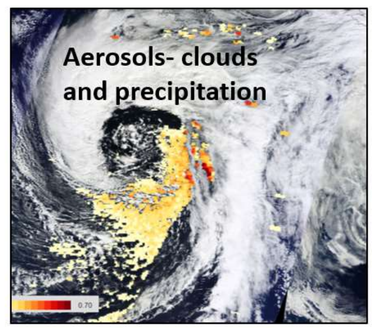
Steering Committee
Co-Chairs: F.M. Ralph
K. Prather, D. Cayan of USCD
+ NOAA, DOE, USGS, NASA
and other Univ. members

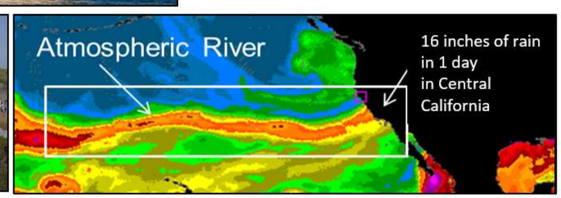
Atmospheric Sci., Chemistry, Hydrology, Oceanography

Ralph et al. 2016
Bull. Amer. Meteor. Soc.









<u>Field seasons</u>

CalWater-1: 2009-2011
CalWater-2: 2014-2016

<u>Locations</u>

California
Eastern Pacific Ocean

<u>Sponsors</u>

DOE, NOAA
California Energy Commission
California Dept. of Water Resources
NSF, NASA, ONR